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THREE SYSTEMS OF WIRE-ROPE TRANSPORT.

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From Selected Papers of the Institution of Civil Engineers.

THE author proposes to describe three systems of wire-rope transport, each of which he has successfully applied on many occasions. The examples, hereafter referred to in detail, are those which in his opinion will give the best idea of the applicability and capabilities of each system. They are:—

(1) An example of the single running rope system, invented by Mr. Charles Hodgson, with improvements by the author.

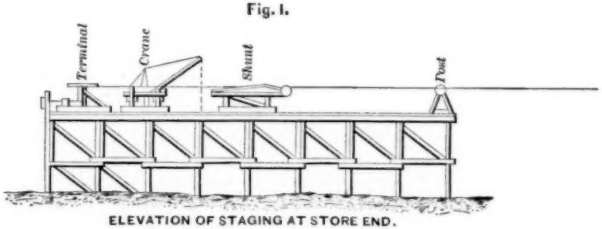
(2) An example of the double fixed rope system, worked on the gravitation plan.

(3) An example of the single fixed rope system.

A fourth system, of two fixed ropes, has been described in the minutes of Proceedings, by Mr. Churchward, Assoc. M. Inst. C.E., in a paper on the Monte Penna Wire Ropeway, lately erected by him from the author's designs.

It is believed the following details will show, that the several systems of wire-rope transport will form a useful and economical means of moving materials in situations where a railway or a road would be too costly or impracticable.

Fig. 1.



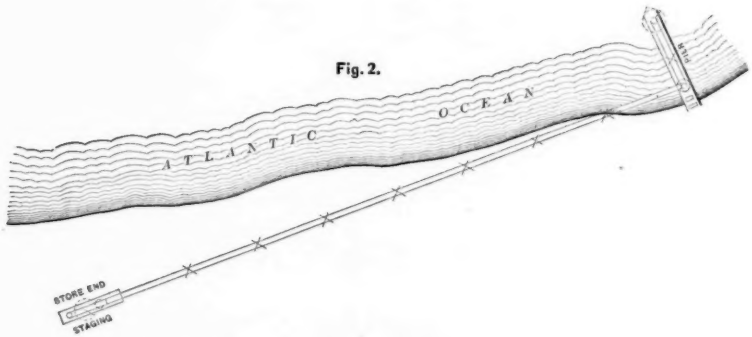
ELEVATION OF STAGING AT STORE END.

RUNNING ROPE SYSTEM.

The example of the single running rope system selected for description is that of a line erected in the cape de Verd Islands, at Messrs. Cory Brothers and Company's coal depot,, shown in Figs. 1, 2 and 3. Its total length is 500 yards, of which length about 320 yards extend along the beach, and about 80 yards at right angles to the longer section to the end of a pier, where the coal is received and despatched. The ropeway was re-

quired to be able to carry 15 tons of coal per hour in either direction, and the motion of the rope was to be utilized in working cranes at each terminal for raising or lowering coal. The coal is brought to the pier, in bulk, in barges from the colliers, and the buckets of the wire ropeway are lowered into the barges

Fig. 2.

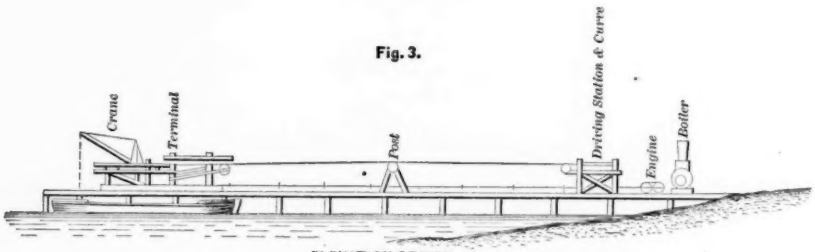


by a crane, and when filled are again raised and sent off on the ropeway to the depot, at its further end, where a quantity of about 10,000 tons is usually stored. To supply the steamers calling at the island the coal is filled at the store into bags holding 2 cwt., raised by a crane to the level of the wire ropeway,

ing round these two drums, and being driven by them. At the lower end of the vertical shaft bevel gear is fixed, by which the motion of the steam engine is communicated to the drums. The usual shunt rails allow the loads to pass round the angle thus formed.

The steam engine is of 16 HP. nominal, has two cylinders, and is fitted with a surface condenser, it being impossible to obtain any fresh water for the boiler in the island except by distillation. The boiler is of the ordinary horizontal multitubular type, cylindrical throughout; it is worked up to a pressure of 60 lbs. The terminal at the end of the shorter

Fig. 3.



ELEVATION OF PIER.

and carried by it back to the barges at the end of the pier.

The driving gear with its steam engine is placed at the point where the two sections of the wire ropeway meet at right angles. It consists of a massive wooden frame, carrying an upright shaft fitted at its upper end with two drums 8 feet in diameter, lying one on the top of the other, the ropes of the sections pass-

section on the pier head carries the horizontal drum round which the tramway rope passes, and a long horseshoe-shaped rail. On this frame is also mounted a crane, having a radius of 17 feet, and worked by shafting from the engine. This crane is manipulated by a friction clutch, actuated by a lever on the top of the frame, on which the man stands and has a clear view of the work going on

below. Four buckets, each holding 2½ cwt., are lifted at a speed of 80 feet per minute, and deposited on to a deck alongside the terminal frame. The buckets are then pushed, singly, down an inclined plane, so arranged that they engage themselves on the hangers which, with their saddles, carry them on the line rope. In a similar way the empty buckets arriving, or the sacks for delivery, are detached and lowered into the barge. The terminal at the end of the longer section at the coal store is placed on a wooden platform, about 20 feet above the ground, and 120 feet long. At the end of this, farthest from the driving station, is fixed a horizontal drum 8 feet in diameter, carried on a strong wooden frame, round which the line rope passes, and which can be drawn back when required to take up any extension. The motion of the rope actuates the drum, which, by a pair of bevel wheels, turns a square shaft, extending along the center of the platform for its whole length. A crane of similar construction to that on the pier head is placed on the platform in front of the terminal, and can be moved from end to end, deriving motion from the line rope through the square shaft at any point. The jib of this crane is long enough to enable loads to be hoisted on either side of the platform, and to be put down just behind the traveling shunt frame, which stands about 15 feet in front of the crane, and which is arranged to slide up and down the full length of the platform in conjunction with it. Thus the sacks of coal, having been raised from the ground, are placed at the foot of the shunt stage, by which they are, having been hung on the hangers, pushed on to the moving rope, and transported to the pier. When coal is being brought to the store, it is tipped into an inclined shoot out of the buckets while they hang on the rail of the moving shunt. It will be seen from the arrangements described that the coal can be hoisted out of the barge at the pier head, transported to the terminal depot, and delivered into store, where it is duly put into sacks for re-delivery to the steamers; and when this is required the sacks of coal can be lifted up to the ropeway, a height of 20 feet, transported to the pier head, and deposited into the barges.

The rope is supported on the longer section by seven posts, which are fixed in the beach, and are of the usual construction, about 15 feet high; these posts carry bearing pulleys 2 feet in diameter, grooved to fit the wire rope, which is of crucible steel of a breaking strain of 16 tons. The rope is run at a speed of 3½ miles per hour. This ropeway is carried about 130,000 tons. Though it was only designed to lift and carry 15 tons per hour, it has on emergencies conveyed more than 25 tons in an hour.

The cost of maintenance of the rope has been about ½d. per ton, that of the machinery about ½d., chiefly owing to the breaking of the buckets by rough use when hoisting. Thus the cost of maintenance may be taken at 1d. per ton, not allowing for the special duty levied on the renewals on entering the island. The cost of labor employed in working this ropeway has been greater than usual, as natives are employed. It amounts to 1d. per ton, including tipping the coal into store, and attending the engine. The cost of working the crane and filling the buckets in the barge has been about ⅝d. per ton. The engine burns 7 cwt. of coal every twelve hours. The operations are generally superintended by an English foreman, who also looks after the other mechanical work on the establishment.

The cost of these works complete erected on the spot, but exclusive of freight and customs duty, was about £2,500, which also included the large staging at the depot, and the woodwork throughout. The whole of the materials were fitted together in England, marked and taken to pieces again. The erection on the site occupied about three months, and was carried out by Mr. W. P. Churchward, Assoc. M. Inst. C.E., from the designs and under the general supervision of the author.

DOUBLE FIXED ROPE SYSTEM.

The first example of the system of transport on fixed wire ropes is that of a series of self-acting inclines of a total length of 2,844 yards, forming a means of conveyance for the lead ore from the mines of the Sentein Mining Company, in the Pyrenees, near St. Girons, France. These mines, which are of great extent and unusual richness, are situated at a height of about 7,000 feet above the sea

near the summit of a mule pass over the Pyrenees. Though they have been worked for many years, their elevated position has prevented them from becoming a financial success, the distance to the dressing floors being 2 miles in a direct line, and the fall about 3,000 feet. Immense expense was incurred by the former proprietors in constructing a cart road up to the mines, which, though extremely steep at many points, and very narrow, required to be about 10 miles long to connect the mines with the dressing floors.

On the property coming into the hands of the Santein Mining Company, the question of transport presented itself as vitally important to the profitable working of the mine. With the road it was possible to bring down by carts about 30 tons per day of lead ore, at a cost of about 8s. per ton, but this was only practicable in good weather, and in winter was impassable owing to the road snow. The Directors of the Sentein Company applied to the author to advise them on the question of applying wire rope transport for the greater part of the distance. He found it possible to recommend the application of a series of self-acting wire-rope inclines (common on a small scale in the district) by which the ore could be brought down to a point about ¾ mile from the works, from whence there was a good cart road. This suggestion was adopted, and wire ropeways were erected from the designs of the author, (Figs. 4, 5, 6 and 7).

The inclines are five in number; the lower terminals of one join the upper terminals of the next, as uitable spot for these junctions being found at the ends or sides of the spurs of the mountain near the line of the wire ropeway.

The lengths and inclinations of the sections are as follow:

No.	Yards long.	Yards fall.
1	271	33
2	675	230
3	410	90
4	978	430
5	510	130
Totals	2,844	913

No. 1 incline commences at the mouth of the mine, and forms a junction with No. 2 incline at the edge of a cliff about 300 feet high. No. 2 incline crosses a span of 675 yards, and joins No. 3 incline on an elevated point on the steep side of the mountain, a small platform being cut out of its side for that purpose. No. 3 incline, stretching across a deep ravine effects a junction with No. 4 incline at the extreme end of a spur of the mountain, a flat space being cut off its pointed top, the sides shelving at an angle of 60° with the horizon. No. 4 incline, spanning a valley 978 yards across, and about 1,500 feet deep, joins No. 5 incline on the side of the mountain. No. 5 incline stretches thence down into the bottom of the valley, terminating close to the cart-road to the works.

These inclines are identical in principle, differing only in length and inclination. They consist of two crucible-steel fixed ropes, of 75 tons breaking strain, anchored at the upper end, and stretched across the space between the terminals, the lower end being held by a pair of blocks fitted with Bullivant's flexible steel-wire rope, by which the fixed ropes are tightened. At each end they pass over a massive masonry saddle. The blocks by which they are tightened are fitted with a long flexible rope, to allow of their being slackened out enough to lie on the ground for the purpose of repairs; the strain put on them is about 12 tons. The carriers for the ore are made of steel plates, measure about 2 feet 9 inches long by 2 feet wide and 2 feet deep, and are hung on the fixed ropes by a curved hanger, fitting into a pair of plates carrying between them two deeply-grooved steel wheels 15 inches in diameter on the tread, which fits the fixed rope. These plates also carry a small wheel under the fixed rope, which is placed so as not to touch it, but to prevent the larger grooved wheels being jerked off.

The carriers empty by the bottoms falling on the turning of a handle fixed to their sides. They are intended to carry from 14 to 15 cwt. each. One of these is placed on each of the two parallel fixed ropes, and the two are connected by a light wire rope of 7 tons breaking strain, of such a length that when one carrier is at the upper end of one fixed rope the other is at the lower end of the second parallel rope. Thus, when one carrier is charged with 14 cwt. of ore while standing on the upper end of the fixed rope, it runs down this rope

dragging up the empty carrier on the second fixed rope by means of the light hauling rope, the speed being governed by a powerful brake. This hauling rope passes round a brake gear at the end of the incline. It consists of two vertical wheels, 5 feet in diameter, having grooved wooden rims, placed 5 feet apart, each wheel being fitted with a powerful brake.

The hauling rope passes over the first of these, next round a wheel 5 feet in diameter, placed horizontally in front at the feet of the two vertical wheels, and then round the second vertical wheel; by this means the adhesion on the two

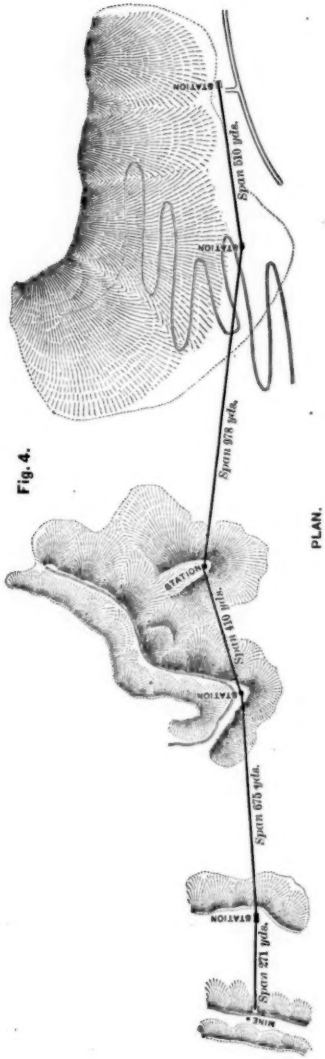


Fig. 4. PLAN.

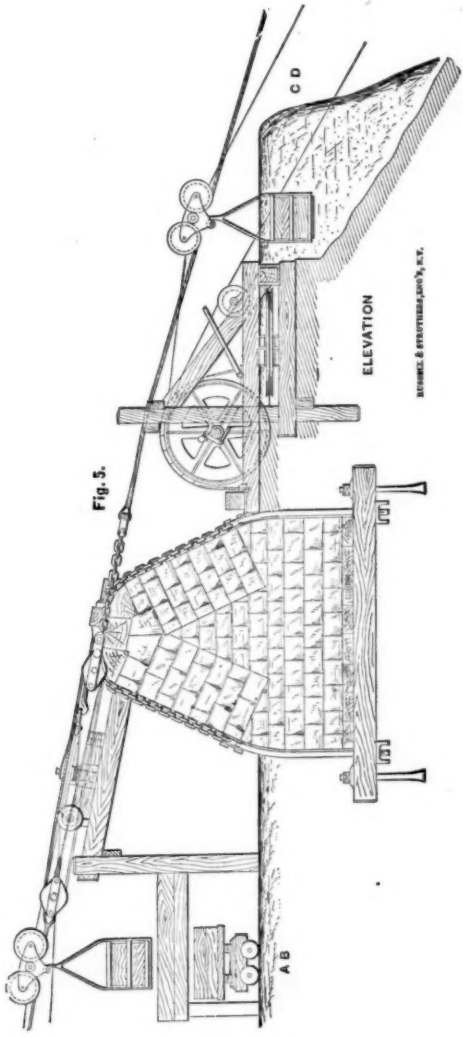


Fig. 5.

vertical brake-wheels is equal to rather more than that derived from two half turns on these wheels. A second hauling rope of the same size connects the carriers by passing round a horizontal drum at the lower end of the incline, which is arranged to be drawn back by means of a screw, to regulate the tension on both the hauling ropes.

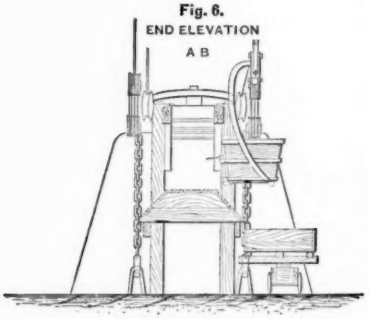
Owing to the great elevation at which most of the stations are situated, the erection of the works was difficult and expensive. The carriage of the ropes up the mountain was especially so; their total was about 30 tons, and it had to be divided into coils of 20 cwt. each, as it was impossible to take up by cart a heavier weight.

In conveying these 20-cwt. coils to the upper parts of the line five horses were required to each, and only one coil per day could be delivered. The transport of the machinery, carriers, &c., was equally difficult and expensive. In building the masonry saddles, owing to the frequent occurrence of frost at night, even during the earlier part of the autumn, it was impossible to place reliance on the mortar used, and the masonry saddles were therefore strengthened with massive timber trestles, fixed round the stonework, which assisted them in taking part of the vertical strain. On a future occasion, in such a situation, it would be advisable to use timber trestles only. By arranging the junctions of the adjoining sections the strain of one balanced to a considerable extent that of the other, and by the anchorage of the fixed ropes of each of these sections to the same foundation beam, which was placed under the saddles, and also strongly bolted down to the rock, the weight of the masonry materially increased their security.

Fig. 6.

END ELEVATION

A B

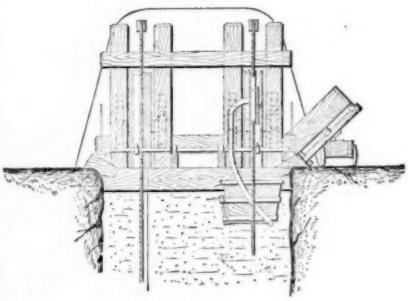


As the inclines joined one another at a horizontal angle, and on very confined spaces of ground, it was found necessary to transfer the contents of the carriers from one section to the next, by small tip wagons running on a short and slightly-inclined rail between the point where the loaded carrier stopped to discharge to that where the empty carrier stood at the top of the adjoining section. These wagons ran easily, with the assistance of one man, who, when he had discharged the contents into the empty carrier, pushed it back into its place, ready to receive the contents of the next loaded one.

Fig. 7.

END ELEVATION

C D



There was, of course, a similar arrangement on each side of each station; had it been possible to obtain better and more spacious sites for the stations, the usual arrangement would have been adopted—of placing the anchorages so that one carrier could tip its contents direct into the empty carrier on the adjoining section, and the lower ends of the fixed ropes could have been anchored by means of weights.

In working these inclines it was necessary to have three men at each station; one man at the brake gear, and the other two men attending to the emptying of the loaded carriers and the transmission of their contents to the empty carriers on the next section. The man at the brake had an uninterrupted view of the whole

section. The speed at which the carriers are allowed to run is about 25 miles per hour; when the brakesmen had become accustomed to their duties, they could regulate their speed to a nicety, and bring the carriers to a standstill at the proper points with perfect smoothness and accuracy.

The quantity of ore which can be transported by these inclines depends, of course, on what can be got over the longest section; and while, owing to the exigencies of the route, it was necessary that the sections should vary greatly in length, it was attempted to equalize their carrying capabilities, by making the longer sections steeper than the shorter ones, thus enabling the carriers to be run on the former at a higher speed. To some extent this was successful. In putting up a series of inclines, such as those now described, it will be advisable to equalize, as far as possible, the carrying powers of each section.

The amount of ore which has been regularly brought down by this system has been from 70 to 80 tons per day, but if sufficient mineral were provided, 100 tons per day could be transported. A trial with the 675 yards section, before the men had become thoroughly acquainted with its working, proved that 12 tons per hour could be taken down. The cost of carriage is about 2s. 0d. per ton, exclusive of maintenance, which may be taken at 1s. 6d. per ton, or a total cost of 3s. 2d. The maintenance charge at these works will be exceptionally heavy, owing to their very exposed situation, and to the fact that for two months of the winter at least no work can be done, the plant, meanwhile, being exposed to the full deteriorating action of the weather.

By this ropeway the transport of mineral has been carried on without stoppage while the roads were buried in snow to a depth of several feet. The works have thus been supplied with ore for a much longer portion of the year than would have been possible by any other means of transport.

The cost of the whole work was about £5,000, of which only £2,200 were for the materials, the balance being for customs duty, freight, delivery from the nearest railway, 25 miles distant, cartage up the mountain and erection.

The work was erected in the nine months, from August to April, during six of which only could work be efficiently carried on, and in the remaining three months the weather and other causes prevented progress. Had the work been commenced earlier in the summer, it could probably have been completed in five months, and much of the erection would have been of far better quality.

SINGLE FIXED ROPE SYSTEM.

The second example of wire-rope transport on fixed ropes is a short length erected at the Nine Elms Works of the London Gas Light Company.

It was required to provide a means of transporting 24 tons per hour of gas coal across a dock in the above works to supply one of the retort houses. The point from which the coal was to be taken was about twelve feet above the ground, and it was required to deliver it into a hopper at the level of about 35 feet, the distance across the dock being 450 feet, and the incline consequently about 1 in 19 against the load. The company's engineer and manager, Mr. Robert Morton, M. Inst. C.E., requested the author to prepare a scheme for his consideration for doing this by wire-rope transport, and finally the arrangement shown by Fig. 8 was adopted.

It consists of a single rope of crucible steel wire, of 40 tons breaking strain, stretched across the dock. The upper end is fixed to a timber framing, attached to the retort house at about 45 feet above the ground, the attachment on which is tied back by another wire rope, exactly in the same line as that over the dock, the end of which is anchored to the opposite wall of the house near the ground. The lower end of the rope across the dock is held by a weight of 4 tons, acting on the double-purchase system, which thus exerts a strain of about 8 tons; by this means the strain on the rope is constant, whether the loaded truck is running on it or not. The truck is made of iron, and holds about 17 cwt. of coal; it is provided with a curved hanger, fitting into a running head which rests on a fixed rope. By a simple arrangement of a lever and catch, the bottom of the truck is let fall, and discharges its contents; the lever and catch are

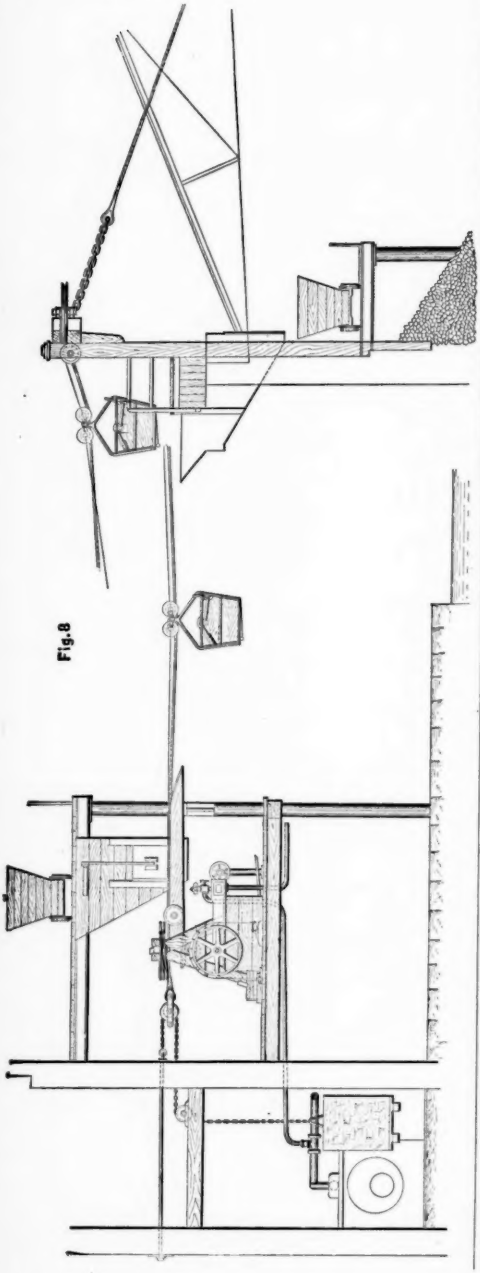


Fig. 8

placed on the side of the truck, and thus the attendant who stands at the delivery terminal can empty the truck and replace the bottom with very little effort and loss of time. At the lower or loading end the truck runs off the rope on to a rail, on which it stands under the door of a hopper containing the coal to be transported. This is let into the truck by a sliding door conveniently worked. The truck is made to stand on the rail under the hopper, in order that it shall be supported rigidly, and at the same height during this operation, which it could not do had it remained on the rope. When loaded, it is drawn across to the discharging end, hanging on the fixed rope by means of the running head, at a speed of five miles per hour, up a nominal incline of 1 in 19, but owing to the bend of the rope this is often as much as 1 in 10. The running head which has been referred to is formed of two strong iron plates, carrying between them, one near each end, two deeply-grooved cast-iron wheels, about 9 inches in diameter on the tread, and made to fit the fixed rope. The edges of their rims are turned true, so as to run on the rail under the loading hopper before referred to. These wheels are carried on steel pins fitted between the wrought-iron plates, through which, between the wheels, the curved hanger attached to the truck also passes.

This head with its suspended truck is moved along the fixed rope by a small crucible steel wire rope of about 4½ tons breaking strain, which passes round a horizontal drum fixed at the upper end of the line to the wooden frame which carries the attachment of the fixed rope, and is put in motion by a simple arrangement of driving gear at the lower end of the line. This driving gear consists of a horizontal wood-rimmed drum driven by bevel gearing, so arranged that it may be moved at 5 miles per hour in the forward, and at 10 miles per hour in the backward direction. The driving drum is fitted with two parallel grooves, and by means of a smaller drum placed at one side of it, the hauling rope may be made to pass twice round certains of its circumference, and thus increase its driving power. This contrivance also gives a means of taking up any small amount

of stretch which may take place in the hauling rope.

The whole of the driving gear is carried on a substantial A-shaped wooden frame, and alongside it is placed a small engine of 6 nominal HP to provide the motive force. All the handles which control the motion of the driving gear, as well as that of a powerful brake on the fly-wheel of the engine, and that by which the loading hopper door is opened, are brought to a convenient spot where the driver can stand, who thus, without moving from his place, has control over all. In case the engine, which is of Tangye's "Soho" type, and of very short stroke, should stop on its center, a ratchet lever arrangement is placed on the end of the crank-shaft, so that the driver can move it off with ease. In working this ropeway it is found that 30 lbs. of steam will drive the engine at the required speed, thus giving 8 HP actual. The labor employed when working to the full capacity is as follows: One driver, one trimmer, and one man at the discharging end.

The method of proceeding is as follows: The truck having arrived under the loading hopper, the driver pulls up the door, and the bucket is filled, the trimmer with a shovel leveling the coal as it falls; the driver, shutting the hopper door, engages the forward motion of the driving gear, and the truck is drawn across to the discharging hopper, about 5 feet square, at the upper end of the line some 450 feet distant; the driver, putting on the brake, stops the motion, and on receiving a signal from the man at the upper end that he has emptied the truck and replaced the bottom, puts the backward gear in motion, and draws the truck back to the loading hopper at a speed of 10 miles per hour. In regular working the whole of the operations described occupy two minutes, and thus 30 runs are made in the hour. At a trial, however, it was found possible to load, transport, and empty, ten trucks in fifteen minutes, or about 30 tons per hour.

Since this line has been at work a small apparatus has been fixed to the driving gear, by which the driver can stop the truck exactly over the hopper. This was previously effected by placing a mark on the hauling rope, but owing to much of the work being done while it is dark, a more convenient arrangement was found advisable.

The labor is paid for at the rate of 0.88d. per ton. The renewal of ropes, wheels, and general maintenance, may be taken at 0.4d., of which the maintenance of the wire ropes is 0.26d. In all, excepting fuel, which in this case is the gas coke on the premises, the cost of loading, transporting for 150 yards up an incline of 1 in 19, and discharging, is 1.28d. per ton. The cost of the machinery ropes and steam engine for this work was £340. The erection and the platforms were provided by the London Gas Light Company.

Such a ropeway is very suitable for transporting materials across a space where supports are inadmissible, such as ravines, rivers, from shore to a pier head, or pontoon in deep water, &c. The loads carried may be as heavy as 20 or even 30 cwt. net, as it becomes, under such circumstances chiefly a question of the strength of the rope. The author, some years ago, erected a similar means of transport over a valley 1,000 yards wide, without intermediate support, and in that case loads of 15 cwt. were moved.

The author trusts that by the examples, he has given of three descriptions of wire-rope transport, he has shown the applicability of the system under circumstances where the use of any other means would be either costly or impossible, and in such cases he believes this system may be advantageously used.

Fine Flooring.—The finest floors are said to be seen in Russia. For those of the highest grade tropical woods are exclusively employed. Fir and pine are never used, as in consequence of their sticky character they attract and retain dirt, and thereby soon become blackened. Pitch pine, too, is liable to shrink, even after being well seasoned. The mosaic wood floors in Russia are often of extraordinary beauty. One in the summer palace is of small squares of ebony, inlaid with mother-of-pearl. A considerable trade is done in Dantzic and Riga by exporting small blocks of oak for parquet floors. There is an active demand for these in France and Germany, but none in England.

THE THEORY AND PRACTICE OF VENTILATING COAL MINES.

By W. FAIRLEY, M.E., F.S.S.

I.

1. MOTION in air is caused by pressure or difference of pressure—pressure is obtained by difference in density—and the movement is in the direction from the heavier to the lighter air. Pressure, or difference of pressure, as regards air circulating in mines, may be obtained either by the application of heat as by a furnace, or by exhausting the air mechanically from the workings by a fan; it is no matter which of these means is applied to procure difference of pressure, the result will be the same with the same difference of pressure however obtained.

2. If there are two shafts of equal depth, having a passage at the bottom connecting them, and the temperature and density of the air are the same in each shaft, then, as there is nothing to destroy the equilibrium of pressure, the air will remain stagnant.

3. If by some artificial means, as by a furnace, the temperature of one of the shafts is raised above that of the other, or there is an exudation of the lighter gases, then the air in that shaft will be less dense, and the air will move in that direction from the colder shaft—the heavier column descending and forcing up the lighter one with a velocity proportionate to the pressure caused by the difference of density.

4. If the tops of the two shafts were not on the same level, the atmospheric pressure would be the same at the same level above the surface, and the extra head of air above the shorter shaft, forming part of the outward atmosphere, would have the same effect as if it were contained in a shaft which rose to the same height. In this case, if the external temperature were lower than the temperature of the strata in which the shafts and the passage were made, the circulation of the air would be down the shorter shaft and up the longer one. On the other hand, if the exterior temperature be higher than that of the shafts and strata, the shorter shaft will be the upcast.

5. The *motive column* is a head of air of such a height that it will equal the difference of the weight between the air in the downcast and upcast shafts; and it is found by calculation from this rule:

$$M = D \times \frac{t_2 - t_1}{459 + t_1}$$

M=motive column D=depth of upcast in feet, t_1 and t_2 represent the temperatures of the downcast and upcast shafts respectively.

6. The motive column is really a measure of the pressure in force producing the ventilation, and if it is required to express it in pounds per square foot it may be calculated by multiplying the depth of the shaft in feet by the weight of one foot of air at the average temperature of the air in the shaft. Do this for each shaft and deduct the one from the other, the difference will be the pressure producing the ventilation. The following table gives the weight of a foot of air at various temperatures, and may be found useful to the student for this and other purposes.

TABLE showing the weight of a cubic foot of air in decimals of a pound avoirdupois, at different temperatures, calculated from the formula

$$W = \frac{1.32529 \times 30}{459 + t} = \frac{39.7587}{459 + t}$$

Temperature t.	Weight in decimals of a lb.	Temperature t.	Weight in decimals of a lb.
32	.0809749	120	.0686678
35	.0804831	125	.0680799
40	.0796767	130	.0675020
45	.0788863	135	.0669338
50	.0781113	140	.0663751
55	.0773515	145	.0658256
60	.0766063	150	.0652852
62	.0763122	155	.0647535
65	.0758753	160	.0642305
70	.0751582	165	.0637158
75	.0744544	170	.0632093
80	.0737638	175	.0627108
85	.0730858	180	.0622201
90	.0724202	185	.0617571
95	.0717666	190	.0612614
100	.0711246	195	.0607931
105	.0704941	200	.0603318
110	.0698746	205	.0598775
115	.0692660	212	.0592529

7. The force which operates in putting air in motion may likewise be expressed by saying it is equal to so much water-gauge, generally expressed in inches and decimals. With air and water at a temperature of 62°, the following rules will apply for converting the pressure into different terms:

Water gauge in inches $\times$ 5.196= pounds per square foot.

Pounds per square foot divided by .0763122=length of motive column in feet

8. The velocity of air without resistance is the same that a body would attain in falling the height of the motive column, so that if there is a difference of pressure equal to 34 ft. of air column, the theoretical velocity of the air would be about 47 ft. per second, because a falling body under the force of gravity, would attain a velocity of 8.025 times the square root of 34, or 47 nearly. It will thus be seen that were it not for the resistances encountered by air in passing along underground roads, a very small pressure would suffice to produce a great velocity. To show the theoretical velocity due to various pressures or motive columns, the table following has been constructed; from this we see that with 2 in. of water gauge, a very common pressure in colliery ventilation, a velocity of 93 ft. per second would be attained, but as air is retarded in its movement by rubbing against the sides of the channels, nothing like the theoretical velocity is reached in practice. The table shows likewise the pressure variously in pounds per square foot, inches of water gauge and feet of air column.

TABLE SHOWING THE AMOUNT OF MOTIVE COLUMN OF AIR AND INCHES OF WATER GAUGE NECESSARY TO PRODUCE THE THEORETICAL FINAL VELOCITY IN UP-CAST SHAFTS, WITH AIR AT DIFFERENT TEMPERATURES

Velocity in feet per second.	Motive column of air.	Water gauge in decimals of an inch at the following temperatures.								
$A=8.025\sqrt{B}$	$B=\frac{A^2}{64.4}$	$C=\frac{\frac{1.32529\times 30}{459+t}\times B.}{5.196.}$								
		Degs. 90	Degs. 105	Degs. 120	Degs. 135	Degs. 150	Degs. 165	Degs. 180	Degs. 195	Degs. 210
5	.39	.005	.005	.005	.005	.005	.005	.005	.005	.004
10	1.55	.022	.021	.020	.020	.019	.019	.019	.018	.018
15	3.49	.049	.047	.046	.045	.044	.043	.042	.041	.040
20	6.21	.087	.084	.082	.080	.078	.076	.074	.073	.071
25	9.70	.135	.132	.128	.125	.122	.119	.116	.113	.111
30	13.98	.195	.190	.185	.180	.176	.171	.167	.164	.160
35	19.02	.265	.258	.251	.245	.239	.233	.228	.223	.218
40	24.84	.346	.337	.328	.320	.312	.305	.297	.291	.284

9. In practice from ten to twenty times as much pressure is required to give that momentum to the air which would suffice for the final velocity, on account of the friction air meets with in rubbing against the sides of the airways in passing round the underground workings.

10. If the whole friction of a mine be measured by 2.18 in. of water gauge, and the final velocity of the air in the upcast is 30 ft. per second—a common enough velocity in furnace shafts—the temperature of which is, say 135°, it will be found by calculation that 2 in. of this pressure is due to friction, the decimal portion only being required to produce the velocity, the water gauge due to final velocity being found thus:

$$\frac{30^2}{64.4}\times\frac{\frac{1.32529\times 30}{459+t}}{5.196}$$

The table given on page 186 has been prepared to show the height of water gauge required to generate the theoretical final velocities at various temperatures; this deducted from the total height of water gauge gives that which is to be referred to friction.

TABLE showing the comparative height of water gauge and air column at a temperature of 62 degs Fahr., with pressure in pounds per square foot and theoretical velocity of air due to this pressure.

NOTE.—Weight of cubic foot of air at 62 degs. =.0763122 lb., and of water =62.355 lb.

Water-gauge in inches.	Pressure in pounds per square foot.	Motive column of air in feet.	Velocity of air in feet per second due to motive column.
A=	B=	C=	D=
B	$\frac{A \times 62.355}{12}$	$\frac{B}{.0763122}$	$8.025\sqrt{C}$
5.196			
.1	.5196	6.81	21
.2	1.0392	13.62	30
.3	1.5588	20.43	36
.4	2.0784	27.24	42
.5	2.598	34.04	47
.6	3.1176	40.85	51
.7	3.6372	47.66	55
.8	4.1568	54.47	59
.9	4.6764	61.28	63
1.0	5 196	68.09	66
2.0	10.392	136.18	94
3.0	15.588	204.27	115
4.0	20.784	272.36	132
5.0	25.980	340.45	148
6.0	31.176	408.55	162

EXAMPLE:—The quantity of air passing in an upcast having an area of 140 ft., is 210,000 cubic ft. per minute; the velocity is therefore 25 ft. per second, the temperature is 210°, then the water gauge due to velocity is by the table equal to .111 inch.

THE RESISTANCE OF AIR IN MOVING ALONG UNDERGROUND PASSAGES.

11. All experiments hitherto made with respect to the movement of fluids of every kind in pipes, passages or channels tend to prove that the resistance to the motion of the fluids is in proportion to the length of the passages traversed, to the perimeter of the section of the passages, to the square of the mean velocity of the fluids, and in inverse ratio to the section, or nearly so.

12. The following rules apply to the friction of air in moving along level passages of uniform size:—Let a = area of airways in square feet; h = horse power of ventilation; k= co-efficient of friction; l = length of air channel; o = perimeter of air channel; p = pressure in pounds per square foot; q = quantity of air circulating in cubic feet per minute; s = area in square feet of rubbing surface exposed to the air; u = units of work, foot pounds or power applied to circulate the air; v=velocity of the air in feet per minute; w=water gauge in inches; then

1.—$a=\frac{ksv^3}{p}=\frac{pa}{p}=\frac{ksv^3q}{u}=\frac{ksv^3}{pv}=$

$\frac{u}{pv}=\frac{q}{v}=\sqrt[3]{\frac{q}{\frac{u}{ks}}}$

2.—$h=\frac{u}{33000}=\frac{qp}{33000}$ &c.

3.—$k=\frac{pa}{sv^2}=\frac{u}{sv^3}=\frac{p}{\frac{sv^2}{a}}=\frac{w5\frac{1}{5}}{\frac{sv^3}{a}}$.

4.—$l=\frac{s}{o}$.

5.—$o=\frac{s}{l}$.

6.—$p=\frac{ksv^3}{a}=\frac{u}{q}=5\frac{1}{5}w=\left(\sqrt[3]{\frac{u}{ks}}\right)^2\frac{ks}{a}=$

$\frac{pa}{a}=\frac{ksv^3}{q}=\frac{u}{av}$.

7.—$pa=ksv^2=\left(\sqrt[3]{\frac{u}{ks}}\right)^2 ks=\frac{u}{v}$.

8.—$q=va=\frac{u}{p}=\frac{ksv^3}{p}=$

$\sqrt{\frac{pa}{ks}}a=\sqrt[3]{\frac{u}{ks}}a$.

9.—$s=\frac{pa}{kv^2}=\frac{u}{kv^3}=\frac{qp}{kv^3}=\frac{vpa}{kv^3}=lo$.

10.—$u=qp=vpa=\frac{ksv^3q}{a}=ksv^3=$

$q5\frac{1}{5}w=h\,33{,}000$.

11.—$v=\frac{u}{pa}=\frac{q}{a}=\sqrt[3]{\frac{u}{ks}}=\sqrt[3]{\frac{qp}{ks}}=\sqrt[2]{\frac{pa}{ks}}$.

12.—$v^2=\frac{pa}{ks}=\left(\sqrt[3]{\frac{u}{ks}}\right)^2$.

13.—$v^3=\frac{u}{ks}=\frac{qp}{ks}=\frac{vpa}{ks}$.

14.—$w=\frac{\frac{ksv^2}{a}}{5\frac{1}{5}}=\frac{p}{5\frac{1}{5}}$.

13. These formulæ comprise the pressure referable to resistance, but not that necessary for producing velocity; so that they may be looked upon as more

correct for long passages than short ones; that is to say, the pressure required for the final velocity becomes a smaller fractional part of the whole drag as the pit workings extend. In a general way, for the sake of simplicity, the student need not take into account the pressure necessary for velocity; but if he desires to do so, instead of using p let him use $p-p_v$; p_v being the pressure required to generate the final velocity. In this case,

Instead of using $a=\frac{ksv^2}{p}$ substitute $\frac{ksv^2}{p-p_v}$.

Instead of $pa=ksv^2$, use $a(p-p_v)=ksv^2$.

Instead of $p=\frac{ksv^2}{a}$, use $p-p_v=\frac{ksv^2}{a}$, or

$$p=\frac{ksv^2}{a}+p_v.$$

Instead of $s=\frac{pa}{kv^2}$, use $\frac{(p-p_v)a}{kv^2}$.

Instead of $v=\sqrt{\frac{pa}{ks}}$ use $\sqrt[2]{\frac{(p-p_v)a}{ks}}$.

14. The co-efficient that will be used in working out the examples given in the following paragraphs will be that adopted by Mr. Atkinson, viz., .0217 lb. per square foot of area of section for every foot of rubbing surface and for a velocity in the air of 1,000 ft. per minute; or .0000000217 lb. for a velocity of one foot per minute, or $\frac{1}{46082950}$.

15. The area of a road, if square or rectangular, is found by multiplying the two sides together; thus a road 6 ft. high and 5 ft. wide = 30 ft. area. The perimeter of the same road would be $2\times6+2\times5=22$.

The rubbing surface is found by multiplying the perimeter by the length; thus a road to continue for 1,000 yards in length, and measuring 6 ft. × 5 ft., would have a rubbing surface (s) of $(1{,}000\times3\times22)=66{,}000$ square feet.

17. The quantity of air in cubic feet per minute is obtained by multiplying the velocity in feet per minute by the area; the horse power is obtained by multiplying the quantity by the pressure and dividing by 33,000.

18. The student must take care to clearly understand the difference between pressure (p) and power (u). Pressure is the force per square foot producing the ventilation, and power is the quantity passing multiplied by the pressure.

19. The co-efficient is found by dividing the pressure by the rubbing surface, multiplied by the velocity squared, divided by the area, or the value of $\frac{sv^2}{a}$ divided in the pressure (p).

20. The resistance is according to the length of the air channel for the same quantity of air, thus, if a mine were extended from 1,000 to 2,000 yards, the resistance would be doubled.

21. The resistance is according to the square of the velocity, and aircourses having the same pressure, area and perimeter, but different lengths, will pass quantities in accordance with the reciprocal of the square root of the length, or the square foot of the length divided into one. Suppose an aircourse 200 yards long pass 7,071 cubic feet, the quantities that will pass in aircourses of 400 and 600 yards long, with the same pressure, area, and perimeter, will be 5,000, and 4,082 respectively, because $\sqrt{\frac{1}{200}}=.07071$; $\sqrt{\frac{1}{400}}=.05$; $\sqrt{\frac{1}{600}}=.04082$ and the fact that lq^2 for each airway gives the same result proves the question.

22. The quantity of air circulating in a mine is according to the square root of the pressure; in furnace ventilation the pressure increases with the depth (provided the difference of temperature between the two shafts be maintained) and the ventilation with the square root of the depth of the upcast, so that by adding a stack of 30 ft. at the top of an upcast 150 fathoms deep the ventilation capabilities would be increased about $\frac{1}{60}$th.

23. If we obtain a certain quantity by a furnace and another by steam jet or other means, the combined effect will be according to the square root of the square of the one added to the square of the other; for example, if a mine circulates 25,000 cubic feet of air per minute by furnace alone, and 22,000 by steam jets alone, the quantity of air that will pass with the two acting together will be be $\sqrt{25000^2+22000^2}=33{,}301$.

24. The quantity of air passing is according to the cube root of the power

applied, and *vice versa*, the power necessary is according to the cube of the quantity; thus to treble the quantity of air in a mine the power necessary would be twenty-seven times as much, and if by an expenditure of 70,087 units of work 16,848 cubic feet be obtained, the quantity that would be got by employing 277,045 units would be 26.639, because:

$$\frac{16848\times\sqrt[3]{277045}}{\sqrt[3]{70087}}=26639$$

25. The quantity of air passing in airways of different areas, other things being equal is according to the square root of the area multiplied by the area. Thus, the pressure and rubbing surface being the same in each case, the quantity passing in an airway of 30 ft. area, when 20,000 ft. pass in one of 60 ft. area, will be 7,071, because

$$\frac{\sqrt{30}\times 20000}{\sqrt{60}}\times\frac{30}{60}=7{,}071.$$

26. To make airways of different lengths of such area as to pass an equal quantity with the same pressure, apportion them according to the formula

$$a=\frac{q}{\sqrt[3]{\frac{u}{ks}}}$$

Thus, in a coal mine ventilated by five different splits or air currents:

The first	200	yards	long	and 9	ft. area,
" second	400	"	"	?	"
" third	600	"	"	?	"
" fourth	800	"	"	?	"
" fifth	1,000	"	"	?	"

The areas of each of these, to pass the same quantities with the same pressure, will be found thus: reckoning the perimeter to be the same in each case, and taking the length in feet as the rubbing surface, and 10,000 cubic feet as the quantity passing in each road, then u will be found for the first airway by $\left(\frac{ksv^2}{a}\right)\times q = 17{,}860$, and the value of $\sqrt[3]{\frac{u}{ks}}$ in each of the other roads is:

2nd, 881.883,
3rd, 770.400,
4th, 699.955,
5th, 649.780, then:

$$2.-\frac{10000}{881.883}=11.339 \text{ area.}$$

$$3.-\frac{10000}{770.400}=12.980 \text{ "}$$

$$4.-\frac{10000}{699.955}=14.286 \text{ "}$$

$$5.-\frac{10000}{649.780}=15.389 \text{ "}$$

and the correctness of these areas is proved by finding the amount of pressure, p, for the assumed quantity, which ought to be the same in each case as below:

$$\left(p=\frac{ksv^2}{a}\right)$$

$$1.-\frac{.0000000217\times 600\times\left(\frac{10000}{9}\right)^2}{9}=1.786 \text{ lb.}$$

$$2.-\frac{.0000000217\times 1200\times\left(\frac{10000}{11.339}\right)^2}{11.339}=1.786 \text{ lb.}$$

$$3.-\frac{.0000000217\times 1800\times\left(\frac{10000}{12.98}\right)^2}{12.98}=1.785 \text{ lb.}$$

$$4.-\frac{.0000000217\times 3000\times\left(\frac{10000}{15.389}\right)^2}{15.389}=1.785 \text{ lb.}$$

which is sufficiently near. Or, as in this question the quantity (q), the power (u), k and q are all the same, we may cancel these factors in the equation $a=\frac{q}{\sqrt[3]{\frac{u}{ks}}}$ which will then be reduced to $\sqrt[3]{s}$, then the areas will be simply according to the cube root of the rubbing surface (s); and, as in this we consider the length as the rubbing surface, because the perimeters are all taken as equal, the result will be according to the cube root of the length, thus:

1. $\sqrt[3]{600} = 8.4343.$
2. $\sqrt[3]{1200} = 10.6269.$
3. $\sqrt[3]{1800} = 12.1644$
4. $\sqrt[3]{2400} = 13.3884.$
5. $\sqrt[3]{3000} = 14.4222.$

We now say:

area.
If 8.4343 : 9 : : 10.6269=11.339 of 2nd airway.
" 8.4343 : 9 : : 12.1644=12.980 of 3rd "
" 8.4343 : 9 : : 13.3884=14.286 of 4th "
" 8.4343 : 9 : : 14.4222=15.389 of 5th "

which areas are precisely the same as those obtained above.

27. If a continuous undivided road passing one current of air be of various dimensions, for the purposes of calculation it may be reduced to one typical road of uniform size throughout, the length (l') of which may be found by this rule:

$$l'=\frac{a'^3}{o'}\times\frac{s}{a^2}.$$

a'=area of typical road; o' perimeter of same, s and a = rubbing surface and area respectively of the original uneven road at each series of dimensions.

EXAMPLE: The following are the measurements of an airway, and it is desired to calculate the length of a typical road which will measure 6 ft. square uniformly throughout, and that will offer equal resistance to it.

With a road 6 ft. square, $\frac{a'^3}{o'}$ will equal 1,944.

Length l. Feet.	Size.	Area. a Feet.	Perimeter. o. Feet.	Rubbing surface. $s=lo$. Feet.	Length of typical road $=l'=1944\times\frac{s}{a^2}$.
700	7×5	35	24	16,800	761.7
300	4×5	20	18	5,400	1312.2
400	8×3	24	22	8,800	1237.5
500	6×5	30	22	11,000	792.
200	4×4	16	16	3,200	1518.6
2,100	Length of Original road.		Length of Typical road.		5622.

Thus we see that the length of the new road would be 5,622, the old one being 2,100 ft.; and this may be proved in the following manner:—Put the quantity of air passing at 10,500 cubic feet per minute, then the pressure (p) for each part of the original road will be found by $\frac{ksv^2}{a}=$

lbs.

Each part of the original road.

1.— $\frac{.0000000217\times16800\times300^2}{35}=.9374$

2.— $\frac{.0000000217\times5400\times525^2}{20}=1.6148$

3.— $\frac{.0000000217\times8800\times437.5^2}{24}=1.5229$

4.— $\frac{.0000000217\times11000\times350^2}{30}=.9747$

5.— $\frac{.0000000217\times3200\times656.25^2}{16}=1.8690$

Typical road:
$\frac{.0000000217\times134928\times291.6666^2}{36}=6.9188$

The correctness of the result is shown by the pressure, p, required to pass the same quantity (which is taken at 10,500) through the typical road, being the same as is required in all the different parts of the original road put together, viz., 6.9188 lbs.

There are one or two useful practical lessons to be learnt from this illustration. In the first place it will be seen that the typical road of 6 ft. square and 5,622 ft. long will offer exactly the same amount of resistance—with the same quantity of air in motion—that is offered by the irregular road, the dimensions of which are expressed in the five series of figures. It is noteworthy that that part of the uneven road measuring 700 ft. long, and 7 ft. by 5 ft., only requires about half the pressure which is necessary to keep in circulation the same amount of air in that portion of the road measuring 200 ft. long, and 4 ft. by 4 ft.; this is of great importance practically and shows how the ventilating power of mines may be used up and wasted, as indeed, it too often is, by contracted airways.

28. The power required to circulate 10,500 ft. of air through an airway 1,000 yards long and 7 ft. by 5 ft., amounts to 42,182 units per minute, whereas the power required to circulate the same quantity through a road the same length, but only 4 ft. square, would amount to 294,368 units per minute. In other words, it would require an engine nearly seven times the power to pass the same quantity through the smaller airway as through the larger one.

29. The relative powers required to pass equal quantities of air through aircourses of the same length, but different areas and perimeters (o) will be found by this rule—$o\left(\frac{1}{a}\right)^3$,—and the table below shows the result of this worked out for five different sized airways:

Size of airways.	o.	a.	$o\left(\frac{1}{a}\right)^3 =$	Relative powers making the road. $6\times6=1$.
6 × 6	24	36	.0005144	1.
5 × 5	20	25	.0012800	2.29
4 × 4	16	16	.0039062	7.59
3 × 3	12	9	.0164608	32.
2 × 2	8	4	.1250000	243.

Thus it will be seen that to pass the same quantity of air through a road 3 ft. square as through one 6 ft. square of the same length will require thirty-two times the power, &c.

30. In a channel or aircourse of uneven area and perimeter along which the air travels in one current, and which in calculation must be taken in a series of lengths of uniform size, the proportion of pressure or power that is taken up by each part of the road will be found by this rule $s\frac{\left(\frac{1}{a}\right)^2}{a}$, or $s\left(\frac{1}{a}\right)^3$

31. The pressure or power required to overcome the friction in passing equal quantities of air through circular airways or shafts is in inverse proportion to the fifth power of their diameters, or directly in proportion to $o\left(\frac{1}{a}\right)^3$.

The table below shows the relative pressure and powers required to overcome the friction in passing the same quantities of air through airways or shafts of the given diameters.

By the table it will be seen that 243 times the power will be required to pass the same quantity of air through a shaft 6 ft. diameter that is required to pass it through an 18 ft. pit, or through airways of these dimensions. The reader will do well to prove this, and he may do so by taking the usual co-efficient, and ascertaining the powers necessary for passing, say, 30,000 ft. of air through two airways, say, of 6 ft. and 18 ft. diameter respectively, and each, say, 500 yards long. This will be found by the rule $u=\frac{ksv^2q}{a}$, which for the 6 ft. diameter channel will be:

$$\frac{.0000000217\times28274.4\times1061.04^2\times30000}{28.274}=$$

732,839 units, and for the channel 18 ft. diameter:

$$\frac{.0000000217\times84823.2\times117.89^2\times30000}{254.469}=$$

30,169 units, and $\frac{732839}{3016}=243$ nearly, which proves the question.

And the quantity of air that will pass in such airways with the same power is in inverse proportion to the cube root of the relative powers; or with the same pressure in inverse proportion to the square root of the relative powers.

Diameter of shaft or airway.	Rule.	Relative powers for the same quantity.
18	—	1.
16	$\frac{18^5}{16^5}=$	1.80
14	$\frac{18^5}{14^5}=$	3.51
12	$\frac{18^5}{12^5}=$	7.59
10	$\frac{18^5}{10^5}=$	18.89
8	$\frac{18^5}{8^5}=$	57.66
6	$\frac{18^5}{6^5}=$	243.

The Chinese are beginning to like the electric telegraph after long objecting to it, and then tolerating it on a small scale in the private line between Mosung and Shanghai. The new line between Shanghai and Chinkiang was completed over two months ago, and has not yet been torn down.

In a paper recently read before the Académie des Sciences on the variations of the resistance of electric machines with their velocity, by M. Lacoine, the author shows reason for thinking these variations are explained by those of contact between the movable commutator and the springs in friction.

IMPROVEMENT OF THE DANUBE AT VIENNA.

A Lecture delivered before the Society of Austrian Engineers and Architects.

Translated by G. WEITZEL, Brevet Major-General, U.S.A.

HIGHLY ESTEEMED ASSOCIATES: Being convinced that you take a lively interest in the great work which has been executed on the improvement of the Danube at Vienna, I will take the liberty to give you detailed information concerning the effect of such works as have so far been constructed in removing the danger of overflow at Vienna, based upon the observations which were made, and the facts which were established during this year's ice-flow and flood.

Since the projects for the improvement of the Danube which have been carried out are sufficiently well known to most of you, my esteemed associates, partly through my lecture delivered before this society on March 11, 1871, and January 2, 1875, and partly by the plans, opinions, and views of experts, which were published in our journal, I do not consider it necessary to-day to enter upon their renewed description.

I will also only recapitulate the chief periods of the formation and final moving of the ice gorges which were formed in the Danube during the past winter in so far as it may be necessary to sustain my arguments and conclusions, since Baron v. Engerth, court counsellor, has already communicated the details in his lecture of last Saturday.

Since the effect of every ice flow and flood can only be clearly appreciated in connection with the extent and position of the former and the height of the latter, I have at first arranged in the following tabular exhibit all of the extraordinary ice flows and floods which have occurred in the Danube at Vienna since 1826, and the highest gauge readings taken during their existence at the three chief stations, *i. e.*, at the great Tabor bridge, Nussdorf, and the Ferdinand's bridge across the Danube Canal.

The corresponding highest gauge readings at Linz and Stein are also incorporated, to enable one to judge whether the high stages at Vienna were caused by floods or by the damming up of the stream by the formation of ice gorges either in the bed of the river or canal.

From this table the following interesting data was obtained, viz:

1. During the period of fifty-one years, between 1826 and 1876, only three summer floods have occurred; but there have been nine heavy ice gorges, attended with floods, caused by the damming of the stream.

The latter are the most numerous, highest, and by far the most dangerous, because the height of water occasioned by them does not depend so much upon the discharge of the stream as it does upon the severity and length of the winter during which the ice gorge was formed, upon the manner and extent of the scourings and fillings caused by the ice in the beds of the river and the canal, upon the condition of the weather which causes the moving of the gorge, and, finally, upon the very weighty circumstance whether the moving of the gorge begins first at the up-stream or down-stream side.

It will be seen from the tabular exhibit that even during low stages in the main stream the water was raised to a considerable height by these scourings and heavy fillings in the beds of the stream and of the canal, and which occasionally have caused the water surface of the Danube Canal to be from 3′ 7$\frac{1}{3}$″ to 10′ 4$\frac{1}{2}$″ above that of the main stream. This was the cause of the destructive overflows which often occurred at the suburbs Leopoldstadt, Brigittenau, Rossau, and Weissgaerber, since several portions of the Vienna Danube Canal banks, as well as many of the streets and grounds in these suburbs, were only situated from 9′ 4″ to 11′ 5″ above the local zero of the gauge.

2. It is universally known that the winter of 1875–'76 was very severe, very long, and very prolific of snow; that on December 9, 1875, already it was neces-

TABULAR EXHIBIT.

Years.	Date of high water	Highest stages in the Upper Danube at— Linz.	Stein.	Date of ice flows and high water	Corresponding highest stages at— Tabor bridge.	Nussdorf.	Ferdnand bridge.	Notes on the ice-flows and high waters at Vienna.
		Ft. in.	Ft. in.		Ft. in.	Ft. in.	Ft. in.	
1829	June 10	10 1¼	.....	.....	.....	.....	.....	
	June 12	.....	13 3¾	June 12	9 2	12 4⅓	12 3⅛	High water in summer.
1830	Mar. 1	14 9⅜	.....	Mar. 1	19 8½	19 2⅛	22 10	The very high stages at these three gauges were caused by the removal of the ice-gorge to the Danube at Vienna and into the Vienna - Danube Canal, there damming the water. Through this the greatest and most destructive inundation of the 19th century, in which many lives were lost, was produced.
	Mar. 2	....	16 1	.....	.....	.....	.....	
1840	July 31	15 6¾	.....	Aug. 2	9 3	12 1¼	12 6½	High water in summer.
1845	Apr. 1	16 6	.....	.....	.....	.....	.....	
	Apr. 2	.....	14 5	Apr. 3	9 2	12 3¼	12 11¼	The ice gorge formed at the Tabor bridge.
1847	Feb. 20	8 5¾	7 5¼	Feb. 20	9 3	9 8¼	14 10⅜	These rises were produced by masses of ice piling themselves upon each other in the Danube Canal as well as in the bed of the stream, and caused considerable overflows of the suburbs of Vienna.
1849	Jan. 16	8 1½	.....	.....	.....	.....	.....	
	Jan. 17	.....	6 11	Jan. 17	8 3½	10 9⅝	18 1⅞	
1850	Feb. 4	13 1¼	14 0	Feb. 4	14 5½	12 8½	14 6¼	
1853	June 20	14 6½	.....	.....	.....	.....	.....	
	June 22	.....	13 0⅜	June 22	9 5	11 11	12 5½	High water in summer.
1861	Jan. 26	0 2	.....	.....	.....	.....	.....	These high stages at Vienna were caused by the moving of the ice gorge into the Danube Canal and stream, in spite of the small discharge of the upper stream.
	Jan. 28	.....	4 10	Jan. 28	10 4⅛	14 0	12 2¼	
1862	Feb. 3	16 2	.....	.....	.....	.....	.....	After the complete and unhindered passing off of the ice gorge, in consequence of a sudden, warm and protracted rain, one of the highest stages was produced, which caused a great inundation.
	Feb. 4	.....	19 2½	Feb. 5	12 2¼	16 5	15 9⅜	
1871	Feb. 11	4 11⅛	.....	.....	.....	.....	.....	The ice gorge was formed at the Tabor bridge and in the canal, and caused a very destructive inundation of the suburbs of Vienna.
	Feb. 13	.....	2 10¼	Feb. 13	9 0	17 4½	20 2¾	
					Emp'ror Francis Joseph's bridge.			
1876	Feb. 17	0 9⅜	.....	Feb. 18	12 11½	14 6¼	14 11½	The gauge at the Emperor Francis Joseph's bridge read 14 feet, but was reduced to the zero of the gauge at the Tabor bridge, *i.e.*, to 12ft. 11½ins. The ice gorge moved partly through the Danube Canal, but mostly through the cut-off, and first stopped above the Northwest Railway bridge, and subsequently above the Stadtlauer bridge.
	Feb. 18	7 10⅞	4 7	Feb. 19	17 5½	At the Reichstrassen bridge.		
	Feb. 19	13 11	13 1¾	Feb. 19	19 4	At the Military Bath.		
	Feb. 20	14 9½	14 9½	Feb. 19	14 6½	At the Stadtlauer bridge.		
		.....	.....	Feb. 20	12 11¾	11 8	10 9¾	

sary to close the lock at Nussdorf by means of its floating caisson in consequence of a heavy ice flow, and that, furthermore, in consequence of the position of the ice gorge in the Danube in Hungary, it had gradually so increased that it reached up to the Reichstrassen bridge; but then again had been shoved back and compressed by the force of the stream.

In consequence of the renewed heavy ice flows from the upper portions of the stream on January 10 and 29, 1876, which, with slight interruptions, continued until February 16, 1876, the gorge was again enlarged and in turn compressed, so that on the date last mentioned the Danube from below Pesth up to about 9½ miles above Tulla, that is, for a distance of about 235½ miles, was full of ice, which, in many places, reached the bottom. This gorge, which was formed in the Danube during ten weeks of a severe winter, may therefore be safely classed as one of the largest, strongest, and most dangerous of any one since the memorable year of 1830.

In consequence of the mild weather which came suddenly in the west of Europe on February 16, 1876, and which produced thaw, with rain, the water in the Danube rose considerably, and the gorge commenced moving above Tulla on the 17th and at Nussdorf on the morning of the 18th, at the time the stage was about 12 feet above zero, and was forced, with the addition of some large masses of ice from the improved stretch of the Danube at Vienna and the Vienna Danube canal, by the high water down to Fischamend, Petronell, and Hainburg. Here the masses of ice were piled high upon each other, since in the lower portion of the stream, in Hungary, the thaw had not yet had its effect and the gorge remained firm.

The circumstances attending such a forcing of an ice gorge by the thaw and high water from Tulla past Vienna and down to Hainburg, must certainly be considered as among the most favorable.

If we do not consider the high stages which occurred during the moving of the ice gorge on account of the partial back water caused thereby, and only those which ensued after the gorge had passed away, we find that the following high stages occurred:

	Ft.	In.
At Linz and Stein on Feb. 20, 1876....	14	9½
At Nussdorf on Feb. 20, 1876.....	11	8
At the Emperor Francis Joseph's bridge, at six o'clock in the evening of Feb. 20, 1876, and before the crevasse in the levee.....	12	11½
At the Reichstrassen bridge on the evening of the same date.....	12	9½

By comparing these with those of former years it will be seen that the stage in the Danube during and after this gorge belongs to the highest since the year 1830, and that therefore this event may be considered as one of the most remarkable ones produced by the elements during a period of 46 years. This is also conclusively proven by the numerous and destructive overflows of the cities situated above and below Vienna, particularly Passau, Linz, Krems, Hainburg, Grau, Waizen, and more particularly Pesth-Ofen. The consequences resulting from a sudden thaw after such a winter, in which much snow had fallen, were not only felt in the Danube, but on the Rhine, Elbe, and Seine, where many cities, and Paris even, suffered from higher and more destructive floods than have occurred since the last century.

3. Since, in former years, even with less extensive ice gorges and at much lower stages of water, the suburbs of Vienna were overflowed, and in the extraordinary gorge and simultaneous high water stages of this year Vienna was exempt from inundation (the flooding of a few low streets and grounds in Erdberg not being considered an inundation), it must be concluded after a thorough study of the present condition of the stream, the phases which were observed, and the data which were collected during this year's ice flow, that the city of Vienna was alone saved from a catastrophe similar to those which occurred here during the fatal years 1830, 1849, 1850, 1862, and 1871 by the improvements of the Danube which have been made.

In order to furnish more detailed proof of the statement just made, I will take the liberty of giving the following facts and observed data:

4. It is universally known that after a strong ice flow the gorge is at first formed mostly in the unimproved stretches of the stream below Pressburg, and then increases in extent up stream to above Vienna, and gradually fills up

the bed of the stream as it did in the past winter. In former years, however, the gorge was occasionally formed in the bend of the stream at the old Tabor and Northern Railway bridge, between their numerous wooden piles, and then extended up stream.

Furthermore, it is the universal experience that the ice gorges which are formed in an unimproved portion of the river, or one that is partly obstructed by bridge piles, can only be lifted and moved down stream by the increased force of much higher stages of water, as was the case at Vienna in 1830 and 1850. In the cut-off at Vienna, which is about 4½ miles long, has the form of a gentle curve, has a cross section about 311 yards wide, and is dredged to a uniform depth of about 10½ feet, no ice gorge was formed during the recent repeated ice flows. When in the beginning of January the ice had massed itself in the cut-off from Fischamend to the ferry, and then to the Reichstrassen bridge, the strong current repeatedly pushed it out and forced it down to Mannswörth. When finally, in consequence of the very heavy ice flow which occurred on January 29, 1876, the ice gorge extended from Pressburg to about 9½ miles above Tulla, the cut-off was, of course, filled up with masses of ice, but yet a strong current of water was still maintained through it, as was clearly apparent by the numerous open channels which were washed out.

When on February 16 and 17, in consequence of the sudden thaw and rain, the gorge commenced moving down from Tulla and from Nussdorf on the morning of February 18, only part of the ice masses which were rapidly piled upon each other remained in the cut-off between the Point and the Northwestern Railway bridge until four o'clock on the afternoon of the 18th. During this time a small part of the descending ice gorge passed under the floating caisson and through the canal, and the greater part passed on the left hand side of the high-water cross section. The latter portions flowed back into the cut-off just below the Northwestern Railway bridge, and moved out rapidly.

At four o'clock on the afternoon of the 18th the masses of ice which were piled up above the Northwestern Railway bridge finally moved where the water had been backed up to the height of about 14′ 5¼″ on the gauge at Nussdorf, and then all the gorge that remained above passed through the cut-off at the 12′ 5½″ stage.

A part of the gorge remained just above the Stadtlau Railway bridge where the cut-off empties into the main stream. This occurred at the spot where the new left hand bank and the new levee on the left hand bank had not been carried across the old bed of the stream. The high water which carried the gorge, and which was confined between dams from Kahlenbergerdörfel down, ran off unimpeded at three places into the old bed of the stream and the left hand channel, and then left the gorge undisturbed.

This change in the location of the gorge caused back water in the cut-off, during the night of February 18 to 19, to the height of 19′ 4″ at the Military Bath; of 19′ 5½″ at the Reichstrassen bridge; of 14′ 6¼″ at the Stadtlau bridge, and 12′ 11¼″ at the Emperor Francis Joseph's bridge.

This gorge passed off already, however, in the direction of Fischamend, during the night of February 19 to 20. A second gorge formed in the lower part of the Weidenhaufen cut-off, which is about 1¾ miles long, about 187 yards wide above the zero, but below that is dredged to a depth of 8′ 3⅜″, and to a width of about 125 yards, and which, for the present, has been left to the effect of high stages of water for its widening, deepening, and completion. This gorge forced the one which came down from the Stadtlau bridge to take the route in the old bed of the stream, which had not yet been completely dammed, at Albern and Kaiser Ebersdorf, in the direction of Fischamend. No injurious effect on the state of affairs at Vienna was caused thereby, but the incomplete dam at the head of the Weidenhaufen cut-off was washed away for a length of 247 feet.

The gorge in the Weidenhaufen cut-off moved on the morning of February 20, at the 13′ 5⅛″ stage. Based upon the foregoing presentation of facts which occurred during the formations, the positions, and the moving of this year's ice gorge, and the coincident high waters, the following conclusions can be drawn, viz:

a. If the cut-off at Vienna had not been

in existence in 1876, and this year's heavy ice gorges, with accompanying high water, had been compelled to pass off by the crooked, irregular old bed of the stream, which is crossed by two wooden bridges and obstructed by numerous piles, it is very probable that a gorge would have been formed here, and the water backed up as high as in 1830. The result would have been an inundation, and possibly a crevasse in the weak levee alongside of the former bed of the "Emperor's" stream, and a consequent destructive overflow of the suburbs of Brigittenau and Leopoldstadt.

The damming of water in the old stream above the Stadtlau bridge to the height of 19′ $3\frac{1}{3}$″ above zero, which actually occurred during this year's ice gorge, would have caused the overflow of the whole Prater and a portion of Leopoldstadt, since the old levee only reached as far up as the Emperor's Mills, and at many places the reference of its top was only16′ $7\frac{1}{4}$″. This was only prevented in the recent case by the banks of earth which were deposited along the new right bank of the stream, by the Commission for the Improvement of the Danube, from the point at Nussdorf to below the Stadtlau bridge. This bank of earth has an average width of from 245 to 410 yards, and its top is in reference 20′ 9″.

b. It will be seen from the tabular exhibit that in former years, whenever ice gorges and high waters occurred, the stage of the Danube at Nussdorf was in every case about 3′ $1\frac{1}{2}$″ higher than at the Tabor bridge; and, further, that in 1830, 1862, and 1871, the stage at Nussdorf reached the height of from 16′ 5″ to 19′ $2\frac{1}{3}$″ above zero, whereby particularly the inundations of the suburbs of Vienna by the Danube Canal were caused.

During this year's extraordinary ice flow and high water, the highest stage at Nussdorf was only during a few hours 14′ $6\frac{1}{4}$″ above zero, and it is particularly due to this considerable diminution in the stage of the river at this point that the high water entered the Danube Canal with a largely reduced pressure.

This diminution in the height of the stage was only caused by the work executed by the Commission for the Improvement of the Danube, which consisted in removing the old works on the left bank of the river opposite Nussdorf, by which the normal cross section was increased in width from $174\frac{1}{2}$ to $311\frac{1}{10}$ yards, in moving back the Hubert levee by which the high-water cross-section was widened from $414\frac{8}{10}$ to $829\frac{6}{10}$ yards, and, finally, by excavating the whole overflowed banks an average depth of 5′ 2″, by which the high-water cross-section of discharge was increased about 10,753 square feet.

c. In former years the stage in the Vienna Danube Canal at the Ferdinand's bridge was at ordinary ice flows and high waters invariably from 2′ 1″ to 4′ 2″ higher than in the Danube at the Tabor bridge, and even attained the height of from 15′ $9\frac{1}{2}$″ to 22′ 10″ above zero in the years 1830, 1849, 1862, and 1871.

During the recent ice flows and high waters the highest stage at the Ferdinand's bridge was during a few hours only, 14′ $11\frac{1}{2}$″ above zero, therefore from $10\frac{3}{8}$″ to 7′ $10\frac{1}{2}$″ lower than in the four years just mentioned, and only 2′ higher than that of the Danube at the Emperor Francis Joseph's bridge. This considerable reduction in the high-water stage is due, firstly, to the reduction made in the heights of the stages at Nussdorf as above mentioned, and, secondly, to the influence of the floating caisson placed at the head of the lock at Nussdorf.

Court Counselor Baron von Engerth has already, on the 11th instant, delivered a detailed lecture on the functions of this floating caisson at the various stages of the formation of the ice gorges and their final moving, and I take the liberty here to mention, for the sake of preserving the connection only, that during the moving of the great ice gorge of February 18 portions of the masses of ice crowded themselves under the caisson, flowed rapidly away by the canal which had been kept thus free from ice; was stopped by the ice masses which had already formed in the bed of the stream at Albern, at the foot of the canal; filled up the bed and formed a gorge in the canal which reached up to the Emperor Francis Joseph's bridge and raised the water in the canal to a height of 15′ $5\frac{3}{4}$″ above zero. The back water of the canal broke through the newly constructed levee on the left bank, whose top was at reference 14′ above and below that bridge, and then, together with the

masses of ice which floated down, poured into the lower part of the Prater.

The water then flowed off along the slope of the valley plain across the Freudenau to the lower end of the same, where it broke through the levee which was in course of construction, in several places, and then emptied itself into the old bed of the stream, which it was intended should be shut off at Albern.

Now, it is undeniably true that, after the completion of the mouth of the Vienna Danube Canal, wherever in future an ice gorge in the Danube is formed reaching from Pressburg to above Mannswörth, and thus closes the mouth of the canal, and then in consequence of a strong influx of ice masses under the floating caisson a piling up of ice masses in the canal and dangerous backing up of its waters might occur, it is necessary that, using the observations made of this year's ice flows and all the experience which has been gained, to make further thorough study and to discover and construct such other contrivances as will enable us, as far as may be necessary, to more completely shut off the flow of ice masses into the Danube Canal under the floating caisson at its head.

This floating caisson also did great service in another respect, in that, after it had been sunk deeper, it caused a smaller quantity of water to flow into the canal during the flood of February 19 and 20, and caused a difference in height of the water surface of the Danube at Nussdorf, and that of the Danube Canal at the Ferdinand's bridge, of from 2′ 0¼″ to 3′ 0⅜″, and this certainly contributed a great deal to preventing the inundation of the lower suburbs of Vienna.

d. The commission for the improvement of the Danube in the period from 1872–'75 also caused the Vienna Danube Canal to be dredged throughout, at its center line to a depth of from 7′ 3½″ to 9′ 4¼″, and on both banks to a depth of 5′ 2½″ below zero; furthermore removed all the bars in the bed of the canal, which were deposited by the creeks emptying into it, and which sometimes extended across the whole bed, and then with this dredged material, which amounted to about 713,640 cubic yards, raised all the lower portions of the banks between Nussdorf and the Emperor Francis Joseph's bridge to a height of at least 12′ 5¾″ above zero, and below the latter to the old mouth of the canal, at the so-called Prater corner, the banks were provided with levees with gentle slopes, whose heights vary from 12′ 5¾″ to 15′ 7″.

By this improvement of the Vienna Danube Canal the circumstances attending its discharges, especially during high water, were considerably bettered, since now the formation of ice masses in it and partial backing of its water cannot occur so easily as formerly. Besides this the very great benefit was secured that at a high water stage of 12′ 5¾″ even the low lands and streets which lie behind the levees cannot be overflowed, whereas this formerly occurred in many places at from 10′ 5″ to 11′ 5¼″ stages.

e. The commission for the improvement of the Danube, in 1873 and 1874, carried the Hurbert levee, on the left bank of the Danube, from Lang-Enzersdorf up stream; raised and strengthened it in a suitable manner, and finally joined it to the foot of the Bisam Hill, although this work was not included in the original approved project. This entirely prevents the discharge of the high waters of the Danube via Lang-Enzersdorf and Floridsdorf and the Marchfeld, a route which was again taken when the crevasse of 1862 in this levee occurred.

How important the reconstruction of this levee was is clearly to be seen from the events of 1874. Although it had been considerably strengthened by that time above its junction with the railroad dam leading to Stockerau, yet this part was in great danger of being broken through by the pressure of the high water, and a crevasse in it was only prevented by works of protection, which were carried on with the greatest energy by night and day.

After a thorough examination and appreciation of the facts and observations which have thus been enumerated, every experienced engineer will agree that the suburbs of Vienna were saved from a great and destructive inundation during this year's extraordinary ice flow and high water by the construction of the works of the Danube improvement alone.

Now, if in addition all of the works for the improvement of the Danube which are begun are once completed, the levees all firmly closed, the enlargement

of the Weidenhaufen cut-off is completed to the normal cross section, the contrivance is added to the floating caisson at the head of the Danube Canal to thoroughly regulate the influx of ice masses, and, finally, when the improvement of the Danube is completed according to the manner suggested in the original project from Mannswörth to below Fischamend, it will be clear to every one that the danger of an inundation of the city of Vienna and of the Marchfeld by the occurrence of extraordinary action of the elements will be still further removed.

The extraordinary ice flow and coincident very high flood, as well as the loading test of the newly erected bridges, have furnished the truest and clearest proof that the project in accordance with which the improvement of the Danube has been strictly executed, and which was made after a correct understanding of the conditions of the stream and in accordance with well-tried elementary technical principles is correct, not only as a whole, but also in all of its details, and that the improvement of the stream has already this year fulfilled its first requirement; *i. e.* the removal of the danger of the inundation of Vienna, and that it will in the future undoubtedly fulfill it in a more brilliant manner.

Furthermore, the well-founded hope exists that the other requirements demanded of this improvement of the Danube, *i. e.*, the improvement of the sanitary condition of the low suburbs of Vienna by the drainage of their surface water, the facilitating and enlivening of the commerce and trade of Vienna, and finally the creation of the necessary room along the new stream for the enlargement of the city, and particularly for the erection of large commercial establishments, will be fulfilled in the same satisfactory manner.

In conclusion, I take the liberty to communicate to my esteemed associates that at the large and important works which have been constructed on the stretch of the Danube between Nussdorf and the Weidenhaufen cut-off, *i. e.*, the five permanent bridges across the Danube cut-off; the ten portions of quay wall whose total length is 1,165¾ yards; the many landing staircases, whose total length is 493⅛ yards; the two large municipal bathing institutes and the large guard lock at Nussdorf (with the exception of a partial undermining of the concrete sole of the lock), not the least damage was caused by the ice gorge and high water, and that the protected banks on both sides were not washed in anywhere, and that they were only slightly damaged at a few places.

This pleasing fact again furnishes the proof that the tracé of the improvement conforms to the conditions of the stream, since it does not give occasion either to the ice gorges or the highly swollen stream to make direct attacks either against these works or the banks, and that these works have good foundations and are solidly built.

I consider that I ought to inform my esteemed associates in reference to the crevasse in the levee, across the old bed of the stream above the Tabor bridge, which occurred on the night of February 20 to 21, *i. e.*, after the ice gorge had moved off, that it did not result from a direct attack of the stream, but was caused by the circumstance that in consequence of repeated high water in the summer and fall of 1875 it was impossible to close the work on the left hand side at Roller before the beginning of winter. The work was, however, prosecuted with the greatest energy by day and night, and this newly piled up and unsettled earth of the levee was very much softened and then broken through by the hydrostatic pressure of the 14′ 6″ stage applied only on one side.

The immediate closing of the crevasse was ordered so as to hold the high water for the purpose of carrying off the ice gorge through the stretch, so dangerous to Vienna, at Nussdorf, and also to secure the two old wooden pile bridges (the Tabor and the Northern Railway) across the old bed of the stream against destruction by the ice.

The result of this precaution was entirely satisfactory, for the gorge which had formed above the Northwestern Railway bridge and had remained there until four o'clock in the afternoon of February 18, was lifted and carried off by the high water, which was firmly held between the levees on the two sides of the stream.

If this levee had not been completed, and the gorge had passed through the old bed of the stream, it is very probable that the two old wooden bridges above

mentioned, which during the last few years have, in consequence of the intended closing of the old bed of the stream, been kept only in poor repair, would have been destroyed by the ice and high water. A greater loss would certainly have resulted from this than the expense occasioned by closing the crevasse in the levee.

5. The question has been raised by some whether the normal width for the cut-off adopted by the commission, and particularly the cross section of discharge, were sufficiently large to carry off, without damage, extraordinary high floods which occasionally occur, and I will therefore take the liberty here to discuss this very important question in detail. In the numerous projects which have been submitted for the improvement of the Danube since 1810, by various hydraulic engineers, only a single cross section of discharge for medium and high stages was adopted, and the following normal widths for the improved bed of the stream suggested, viz:

	Yards.
By Schemerl, director of the imperial board of public works in 1810, for the cut-off	414.56
For the total clear water-way of the proposed permanent bridge	601.46
By the former imperial and royal counsellor of public works in 1817, for the width of the united Danube	372.09
By Kudriaffski, director of hydraulic works in 1830, for the width of the united Danube, said to be based upon experiments and calculations	393.68
By Francesconi, imperial and royal counsellor of public works in 1847, for the clear water-way of the united Reichstrassen and Northern Railway bridge at Floridsdorf	452.74
By van Pasetti, imperial and royal ministerial counsellor in 1859, for the united Danube above Nussdorf	414.56
But from Lobau to Fischamand only	393.68

From this statement it is seen that the above-named hydraulic engineers who had been engaged on works on the Danube, at Vienna, during periods of from 20 to 40 years, made very different suggestions as to the normal width to be given to the stream.

The experts who were called together in 1867, and who declared themselves in favor of the improvement of the Danube by means of excavating a cut-off, recognized the necessity, in order that a good stage of water should be maintained in the improved river, that there should be a special narrow bed for the discharge of low and medium stages, and a second enlarged so-called high water cross section for the discharge of high stages. Upon this, these experts, having studied the older maps of the Danube and the state technicists, having communicated to them the circumstances attending the discharge of the Danube, proposed 345.57 yards for the normal width of the cut-off for low and medium stages, and 829.12 yards for that of the high water cross section. This proposition was adopted by the commission for the improvement of the Danube which existed at that time.

Based upon the thorough studies of the circumstances attending the discharge of the Danube which were concontinued by me, and the fact which was thereby established that the discharge of the stream at low and medium stages had decreased during several decades in a remarkable manner, I submitted a proposition on May 24, 1872, to the commission, that the normal width of the cut-off between the edges of its two banks should be confined to 302.92 yards, but that the width of the high water cross section be retained at 829.12 yards, and at the same time furnished them with the calculations based upon hydraulic formulas on the motion of water in river beds, showing that this modified cross section would be quite adequate for the unimpeded discharge of the medium and high stages.

The commission called together seven distinguished hydraulic engineers, among them two foreigners, to decide this highly important question, and then, after an almost unanimous opinion from them, restricted the normal width of the cut off for low and medium stages to 310.57 yards and retained the width of the high water cross section at 829,12 yards.

In accordance with these widths the cut-off, the high water cross section, and the levees on both banks were constructed so that the cross section of the stream intended for low and medium stages is smaller, but that for high water is very much larger than those proposed by the above named five hydraulic engineers.

I believe that I should now show that the cross section of this improved portion of the stream, which has been car-

ried out, is fully adequate to the unimpeded discharge of even the highest floods.

According to the measurements made by Kudriaffski, director of hydraulic works, the discharge of the Danube at Vienna should be per second:

	Cubic feet.
At the zero stage	70,269
At the 4′ 10″ stage	146,187
Where the banks are full, that is, at 12′ 5½″ stage	256,638

I could not ascertain from public documents the time in, the place where, or the manner in which these measurements wers made.

The former imperial and royal ministry of commerce and public works charged Mr. Nicolaus, who was at that time inspector of hydraulic works, with measuring the discharge of the Danube in 1850 and 1851, at Nussdorf and about 2¼ miles further up at the Kuchelau, in regular cross sections four times daily, and with the greatest possible accuracy. He found that the discharge per second was as follows, viz:

	Cubic feet.
a. At the 1″ stage above zero at the cross section at Nussdorf	55,861
b. At the 2″ stage above zero at the cross section at the Kuchelau	56,426
c. At the 2′ 8″ stage above zero at Nussdorf	74,293
d. At the 2′ 9″ stage above zero at the Kuchelau	81,921

These results may be considered perfectly reliable, because the manner of measurement was entirely rational; furthermore, because Inspector Nicolaus is known to all the older officers in charge of public works to have been an experienced hydraulic engineer and as a man who executed all works intrusted to him with conscientious accuracy; and, finally, because the discharges measured at Nussdorf and the Kuchelau so nearly agree.

It appears from these measurements that the discharge of the united Danube above Nussdorf at the zero stage is about 55,000 cubic feet per second, and that, therefore, this discharge given by Kudriaffski, *i. e.*, 70,000 cubic feet per second, is clearly about 20 per cent. too high. That the discharge given by Kudriaffski, when the banks are full, at the 12′ 5⅓″ stage, *i. e.*, 256,638 cubic feet per second, was not measured, but either estimated or approximately calculated, is apparent from the fact that since 1826 there has not been so high a stage at Vienna; furthermore, because there are no places in the vicinity of Vienna where there is a complete cross section with banks 12′ 5⅓″ high; and, finally, because during such an extraordinary high stage the velocity of the stream is so great that it would be almost impossible to measure a cross section and take the velocity at many points and at different depths thereof.

The Hungarian hydraulic engineers have, in former as well as in latter years, repeatedly measured the discharge of the Danube at different stages, and with the greatest possible accuracy between Pesth and Ofen, where the concentrated river flows between high banks, and, on account of its smaller slope, has a smaller velocity.

The distinguished engineer Reitter, ministerial councillor, had the kindness to send to the Society of Austrian Engineers and Architects the result of these measurements, as well as the gauge-readings from 1857 to 1873, from which I will only select the following as being very interesting to us.

By comparing the gauge-readings at Vienna and Pesth during the period from 1855 to 1867 it will be seen that when the river has reached the zero of the guage at the Tabor bridge the corresponding stage observed two days later gives a reading of from 5′ 5⅓″ to 6′ 4¾″ above zero at the gauge at Pesth, and that the mean of the gauge-readings at Pesth during a period of nine years, where the river had arrived at zero at Vienna was 5′ 9″.

Since the discharge of the Danube at Pesth at this stage was determined by measurement to be 59,604 cubic feet, and since the small tributaries of the Danube between Vienna and Pesth discharge into it at a low stage hardly more than 4,604 cubic feet per second, the measurements of discharge made at Pesth prove the measurements made above Nussdorf by Nicolaus, inspector of hydraulic works, to be more nearly correct.

According to the tabular exhibit given at the beginning of this paper, it appears that the highest stage of water which has occurred since 1826 at Vienna without an ice gorge was on February 5, 1862, when the gauge reading was 12′ 2¼″

above zero; this passed off between Pesth and Ofen on February 7 and 8 with a constant gauge reading at that point of 15′ 8¾″. Now, since according to the report of the ministerial councillor, Reitter, which was furnished us, the measurements made between Pesth and Ofen show that at the 15′ 8¾″ stage the discharge of the Danube is there 184,462 cubic feet per second, and when it is considered that between Vienna and Pesth the tributaries March, Leitha, Raab, Waag, and Grau, must have discharged in the high stage during the period from February 5 to 8, 1862, more than 5,932 cubic feet per second, it follows that during the high stage of February 5, 1862, the discharge of the Danube at Vienna could not have been greater than about 178,530 cubic feet per second. Comparing this with the statement of Kudriaffski, director of the hydraulic works, who, it is true, assumed a stage 3½″ higher, there will be found a difference of 79,108 cubic feet.

In order to prove that the cross section, according to which the cut-off at Vienna was actually executed, is fully adequate to discharge the quantities of water which, as has been shown, pass through, my associates will please make the following hydrotechnical calculation with me.

The latest and most reliable hydraulic equation to determine the velocity of water in rivers and streams is that of Gauquillet and Kutter, which has for Austrian measures the following form, viz:

$$v = \left\{ \frac{41 + \frac{1.779}{n} + \frac{0.00276}{J}}{1 + \left(41 + \frac{0.00276}{J}\right)\frac{n}{\sqrt{R}}} \right\} \sqrt{RJ}$$

In this equation v denotes the mean velocity of the stream throughout the whole cross section; J the slope of the stream; R the mean depth which is obtained by the dividing of the arm of the cross section F by the wetted perimeter U, and finally, n, a coefficient obtained by experience, and which depends upon the friction of the material which forms the wetted perimeter.

The discharge per second, M, is obtained by multiplying the area of the cross section F by the velocity of the stream v, *i. e.*, $M = F\,v$.

Since the average slope of the water in the cut-off at the zero stage is J = 0.0004427, and the coefficient of friction, according to the experiments made by Strauss, at Speyer on the Rhine, and by Destrem, on the Neva, can be taken at $n = 0.026$, we will obtain the discharge as follows:

I.—*At the zero stage.*

It will be found from figure I that the area of the cross section F=8320 square feet

$$U = 856.72'\ R = \frac{F}{U} = 9.7114'$$

hence $v = 5{,}467'$

and $M = 5077$ cubic feet.

Now, since about 3,354 cubic feet per second of the discharge above Nussdorf are carried off through the Vienna Danube Canal, and about 1,677 cubic feet per second are drawn off at Greifenstein for irrigating the Marchfeld, it will be seen that the cross section of the cut-off which has been adopted is quite adequate for the discharge of the low and medium stages.

II.—*At the 12′ 5⅓″ stage.*

Although during the high stage especially when it is rising, the slope of the stream is generally greater than at the zero stage, yet I will assume this slope as unchanged, and call

$$J = 0.0004427.$$

Furthermore, at high stages, the discharge of the stream through its normal bed must be calculated separately from that over its overflowed banks.

For the normal bed we will find—

$F_1 = 18940$ square feet $U_1 = 909'$

$$R_1 = \frac{F_1}{V_1} = 20.83€'$$

therefore $v_1 = 8.754'$

$M_1 = F_1\,v_1 = 184992$ cubic feet.

For the portion of the cross section above the overflowed banks we find—

$F_2 = 69.96$ square feet $U_2 = 1480'$

$$R_2 = \frac{F_2}{U_2} = 4{,}727'$$

therefore $v_2 = 3.382'$

and $M_2 = 26412$ cubic feet.

The capacity of the cross-section for discharge at the 12′ 5⅓″ stage, where the

water just reaches the top of the right-hand bank, is therefore—

$M_3 = M_1 + M_2 = 211{,}404$ cubic feet.

Consequently about 32,900 cubic feet more per second than the discharge of the Danube at Vienna during the highest flood on February 5, 1862.

Now, if it will be further taken into consideration that of the high water which passes Nussdorf about 15,600 cubic feet per second are discharged by the Vienna Danube Canal, and it is still further considered that, as shown by my lecture of March 11, 1871, after the improvement of the Danube to Fischamend, and the inevitable equalization of the slope which will ensue, the zero will be lowered in the cut-off at least from $1\frac{1}{2}''$ to $2''$, which is equivalent to raising its banks to that height, I believe that every experienced hydraulic engineer will agree with me that the normal widths and the cross section of discharge which have been adopted are adequate for the unimpeded discharge of the highest floods, and that these will never rise over the $12'\ 5\frac{1}{3}''$ high-water bank.

As a protection against the backing up of the water which may now and then be caused by the ice gorges, but which will not occur so often on the Danube where it is improved, and will not rise so high, the levees on each bank have been built to a height of $20'\ 9''$ above zero.

Now we will see what observations were made during the high water which came immediately after the gorge moved on the afternoon of February 20.

Although the gauge readings of Linz and Stein were not as high on February 19 and 20, 1876, as those on February 3 and 4, 1862, yet, I believe that in consequence of the sudden melting of the large masses of snow between Linz and Vienna, which was caused by a warm and steady rain, that the high-water discharge at Vienna was as great on February 20, 1876, as it was during the highest stage of 1862. During this year's high water the following gauge readings were taken at 6 p. m. on February 20; that is, before the crevasse in the levee at the Tabor bridge occurred, viz:

	Ft.	in.
Above Nussdorf, where the whole new cross section of discharge was completed	11	8
At the Emperor Francis Joseph's bridge, above the new zero	14	
And therefore above the old zero at the Tabor bridge	12	$11\frac{3}{4}$
And finally at the Reichstrassen bridge.	12	$9\frac{1}{4}$

The reason that the gauge readings were higher at the last two mentioned bridges than at Nussdorf is that in the cross section of discharge at the former bridges the old spoil banks and the old Prague Reichstrassen dam had not been completely removed, and the six houses which stood there had not been torn down, and, furthermore, because the scaffolding, laborers' barracks, restaurants, bath houses, and an elevated railway for the transportation of the material for completing the Reichstrassen bridge still remained, and, finally, because some masses of ice had been shoved on to the banks just below the Reichstrassen bridge, and still remained.

On this account the discharge of the stream was considerably impeded, and its surface raised.

It will be clear to every expert that if the high-water cross-section of discharge along the whole cut-off had been as completely open and unobstructed as at Nussdorf, the high-water mark of this year in the cut-off would not have gone beyond $11'\ 8''$ above zero, from which it will be seen again that after the works on the improvement of the Danube at Vienna are once completed that the cross section of the discharge will be adequate for the highest floods that will occur.

The high water of February 20 lasted, with slight variations, until February 24, and the high-water marks at the different places were as follows, viz:

At Linz, from $13'\ 8''$ to $14'\ 9\frac{1}{4}''$.

At Stein, from $14'\ 6''$ to $15'\ 6\frac{3}{4}''$.

At Greifenstein, from $11'\ 11''$ to $12'\ 5\frac{1}{4}''$.

At the Kuchelau, from $14'$ to $14'\ 8\frac{1}{4}''$.

At Nussdorf, from $11'\ 5''$ to $11'\ 10''$.

*At the Emperor Francis Joseph's bridge, from $9'\ 7''$ to $10'\ 1\frac{1}{4}''$.

*At the Ferdinand's bridge, in the Danube Canal, from $10'\ 3\frac{1}{2}''$ to $11'\ 1\frac{3}{4}''$.

From this it will be seen that the high water of this year lasted a long while.

I now hope that my esteemed associates, afer a thorough examination and consideration of the facts and data which

*At these two bridges the water was considerably lowered by the crevasse.

have been given by me concerning this year's inflow and high water and the hydraulic calculations which I have added, will agree with me in the conclusion that the city of Vienna was alone saved from disasters, similar to those which occurred so often in former years, by the works on the Danube improvement, and that after these are thoroughly completed the protection of the city of Vienna against the danger from overflow will still be far more complete.

Finally, I beg you, my esteemed associates, to allow me to refer to the unfavorable opinions which have been published in many newspapers, partly upon the project for the improvement of the Danube and partly upon the effect of the works which have thus far been completed.

Since I and my professional colleagues have not time to reply to all attacks in the separate journals, we will leave them unanswered, in the hope that a true appreciation of the favorable effect of the works which have thus far been executed will in the end compel recognition.

The results of those one-sided statements and unwarranted attacks on the Danube improvement, have, however, not remained unnoticed.

At first I received letters from my friends in the provinces, in which they try to console me for the total failure of the works, as represented in Vienna journals.

The *Times*, in its issue of February 25, 1876, contains a communication from its correspondent in Vienna concerning the executed portion of the Danube improvement, in which he says that this great work has not fulfilled the hopes of its projectors, and that, on the contrary, it must be considered a total failure, since during this year's ice-flow the inundation of the suburbs Rossau, Leopoldstadt, Erdberg, and the country in the direction of Simmering was just as great as in former years, and that even the new central cemetery was so flooded that the corpses floated out of their graves, and that it was necessary to suspend interments in it during a long period.

Esteemed associates: You see how by such untrustworthy reporters, whose judgment of the project for the Danube improvement is based upon incorrect information and want of knowledge, this successful undertaking, which was much praised during its erection not only by the international jury, but also by more than twenty distinguished foreign engineers, and upon which Austria and Vienna may look with pride and satisfaction, is placed in bad credit and lowered in the estimation of foreigners.

I desire to refer particularly to an anonymous pretended expert who has already, in four articles published in the New Free Press, and entitled "The inundation and its causes," and based upon incorrect data and imaginary hypotheses, designated the whole project for the Danube improvement as a failure, and states even that the works which have been executed were the cause of the pretended inundation of Vienna.

Such a one-sided abuse, for I can no longer call it criticism, of the whole undertaking is so much the more to be regretted since the New Free Press is one of the most respectable papers in Austria, and is the most widely distributed in foreign countries.

In the short time allowed me I cannot recount and correct the many erroneous statements, defects, and charges made by the anonymous expert against the Danube improvement, but I hope you will permit me to point out some of the most glaring defects, since I am convinced that this alone will easily enable you to form an opinion of the knowledge of hydraulics possessed by this expert, and of his one-sided censure of the project for the Danube improvement.

1. The anonymous expert believes that the Danube cut-off was simply traced in plan as a curve to please the eye, without regard to the natural conditions which govern the bends of streams, and that thereby the resistence of the forces of nature was developed. He cannot justify the moving of the river nearer the city, and intimates that it would have been more advantageous to have allowed the Danube to remain in its old bed at Floridsdorf.

Gentlemen: In my lecture of March 11, 1871, I communicated to you that after a dispute lasting through a period of fifty years, and in which twenty-eight of the most distinguished native and foreign hydraulic engineers took part, it was finally concluded in 1867, to the great joy of Vienna and Lower Austria,

to improve the Danube by a cut-off. This conclusion was approved on all sides.

Now, after this cut-off has been made at great expense, repays itself bountifully, and has proved itself during the recent events caused by the elements, as very advantageous, this anonymous expert, plainly without any knowledge of antecedent proceedings and works of experts, utters this oracle, that there was no need of a cut-off, and that it would have been better, therefore, to have left the stream in its bend at Floridsdorf.

You will find it, esteemed gentlemen, quite natural that I do not now enter upon a discussion of such an oracle.

2. The anonymous expert states that the old bed of the Danube had a depth of 20′ 9″ below zero, and since the cut-off was dredged only to 10′ 4½″ below zero, the water must raise itself up in order to get into the cut-off, and then besides that in the shallow cut-off the formation of ice and ice gorges was more extensive, and that consequently the water of the stream was forced through the Danube Canal. Based upon these premises he makes the following assertion, viz: "The new cut-off forms throughout its whole length an artificially constructed dam of earth in the old channel." He further says that the cut-off in its present condition is not only of no assistance in removing the danger of overflow, but is even an absolute obstacle against the free flow of the ice and water.

I must at first remark by way of correction, that the premises of this expert are entirely incorrect, since the depth of water in the Danube in its old bed was only 20′ 9″ in the concavity of its bends, but in the stretches between these, and even in the channel, the depths did not exceed from 6′ 2¾″ to 7′ 3″, and the arithmetical mean of the depths taken on seven different cross sections was found not to exceed from 9′ 4″ to 10′ 4½″ below zero; furthermore, I have shown in this lecture that the ice-gorge never came to a stand in the cut-off, but that in every case it formed from Pressburg upward, and naturally, therefore, the cut-off was filled with masses of ice.

It is also well known to you, my esteemed associates, that it is customary in making a cut-off to excavate a trench of from 62½′ to 124⅔″ in width and about 3½′ in depth, and to leave its further deepening and widening to the power of high waters.

The commission, on the contrary, in order not to expose the city of Vienna to the danger of an overflow during the progress of the work, at great expense, and by the use of a suitable plant, caused the cut-off to be dredged throughout its whole length of about 4⅛ miles, to its whole width of 311⅛ yards, and to the depth in its upper half of from 10′ 4½″ to 11′ 5″, and in its lower half of from 8′ 3½″ to 10′ 4½″ below zero.

I must, before proceeding further, admit that I do not know of any case in which such a colossal cut-off was dredged throughout its whole length, breadth, and depth, and yet this complete construction of the cut-off seems still too small to this anonymous expert, and he censures those in charge of the work with sharp, insulting words for having thereby exposed Vienna to the danger of an inundation.

My esteemed associates will agree with me that these assertions of the pretended expert, and particularly his utterance, printed with large type, that the new cut-off throughout its whole length is an artificially constructed bank of earth in the old bed of the stream, are technically and logically very incorrect, and are only calculated to lower the work in the eyes of laymen, and to awaken in the latter a totally ungrounded fear of danger from overflow.

3. This anonymous expert has also uttered the following oracle, *i. e.*: If the floating caisson had realized the expectations of its inventor, the inundation would have reached an unprecedented height, the water and ice, whose natural flow was obstructed, would have taken the next best route through Nussdorf, and the Danube might possibly have again taken possession of its old bed along the Salzgries, which it left hundreds of years ago.

If that portion of the masses of ice which came down from Klosterneuburg, which passed into the canal under the floating caisson, had been shut out by the latter it would also have passed off over the overflowed banks, which are 518⅛ yards wide, and its flow would only have been delayed several hours.

Furthermore, if after the ice gorge which formed below the Point had been raised and moved through the cut-off at 4 o'clock on the afternoon of February 18, by the damming up of the water to the height of 14′ 6¼″ above zero, it is probable that if no masses of ice, and but little water, had passed into the canal under the floating caisson, this backing up to the height of 14′ 6¼″ above Nussdorf would have occurred several hours sooner and would have carried its whole ice-gorge through the cut-off.

But even in case the floating caisson had completely closed the head of the canal, and, in consequence thereof, the water at Nussdorf would have been backed up 1′ 0½″ or 1′ 6½″ higher, that is, to a height of 15′ 6¾″ or 16′ 0¾″ above zero, no danger would have thereby resulted to the Nussdorf dam on the right bank, for this mighty dam resisted the water successfully in the years 1862 and 1871 where it reached the height of 16′ 5″ and 17′ 4½″.

From the preceding it will be seen that the anonymous expert surely does not himself believe in his oracle, and that he only wrote it to create a sensation and to array non-professionals against the improvement.

4. This expert further insists upon it, that in preparing the project the discharge of the stream had not been ascertained, and that even to-day, when the most of the work may be considered completed, the discharge through the constructed cross section is not known. That this assertion is a clear falsehood is undoubtedly apparent to you, esteemed gentlemen, from that which I have already said.

I do not believe that I ought to touch further on the numerous other slips and defects of the anonymous expert, since you, my esteemed associates, have already gained the conviction from the points which I have mentioned that he, either through ignorance, or based upon intentionally incorrect data, made, technically, entirely incorrect, clearly one-sided assertions and conclusions only with the intention of disparaging the work which has been done, as well as the engineer intrusted with its charge, in the eyes of our fellow citizens, without thinking, however, that by so doing he has brought this national enterprise in discredit in foreign countries, and has thus injured the interests of Vienna. This leads me to the conjecture that he is no Austrian, and at least, not a patriot.

If the esteemed Society of Austrian Engineers and Architects should select a committee to gain a thorough understanding of the working of so much of the work as has been executed, I will take the liberty to make a motion that this committee be requested to thoroughly examine the assertions and complaints of this anonymous expert in the four newspaper articles to which I have referred, and to give an opinion thereon.

THE STORAGE OF ELECTRICITY.

By SYLVANUS P. THOMPSON, B.A., D.Sc., Professor of Experimental Physics in University College, Bristol.

From the "Journal of the Society of Arts."

SCIENCE has of late made two advances, the ultimate importance of which it would be difficult to overestimate. Not many months before he was seized with the mortal illness which robbed us too soon of his rare and unique genius, Professor Clerk Maxwell was asked by a distinguished living man of science what was the greatest scientific discovery of the last twenty-five years. His reply was: "that the Gramme machine is reversible." His far-reaching and philosophic mind had perceived that in this phenomenon, which to so many had seemed little more than a curious scientific experiment, lay the principle which, if rightly developed, would render possible the electric transmission of power, and, in the solution of this practical problem, bring about social and economic changes, the importance of which but few of us have even yet begun to realize.

If we could to-night summon up the noble spirit of the philosopher, and ask

him to tell us what recent scientific discovery came next in importance to this, I think we should receive the reply, "that a voltaic battery is reversible." The reversibility in the action of the voltaic cell is the counterpart and complement of the reversibility of the Gramme machine; for while the one has solved for us the problem of the *electric transmission of power*, the other has solved for us the problem of the *electric storage of energy*.

The storage of energy in such a form that it shall be available for producing electric currents, and for the electric transmission of power, is a fact of so great importance, both in science and in commerce, that no apology is needed for bringing the subject before the Society of Arts. But the electric storage of energy, which is the end attained, must not be mistaken for the storage of that subtle agent electricity itself. A century ago it was thought that the Leyden jar provided a means of bottling up electricity itself. In one sense this may be true, though the fact remains that, the more carefully we hunt for the charge of electricity condensed in the jar, the more difficult does it become to realize that there is anything there; and it is doubly difficult to find, in the electric *accumulator* or *storage cell*, anything which can be called stored electricity. In electric accumulators, such as those of Planté and of Faure, electric currents are made to do a certain kind of work, which store of work can again yield us currents of electricity. But, as a matter of fact, the particular kind of work done is, as we shall see, quite as much chemical as electrical. Just as in Sir William Armstrong's hydraulic accumulators, water forced into a vessel with a great pressure furnishes a means of storing mechanical power under such conditions that when we let it down it can do work for us; so in the electric accumulator, by which we want to store electric currents, we use a chemical storage, and the chemical work so stored can itself, as it runs down, set up electric currents in our wires and do electrical work for us.

Before dealing with the various systems of electric storage that have been suggested, I purpose to lay down two important general principles. They are as follows:

Firstly, that no kind of storage of energy, mechanical or electrical, is possible, except by doing work in overcoming some force which itself opposes the process.

Secondly, that the action in which work is thus done, must be one that is reversible; that is to say, to which there is an equal and opposite reaction.

ELECTRICAL ACTION AND REACTION.

"To every action there is an equal and contrary reaction." In these words Newton laid down the great fundamental principle of mechanical science. Its application is not limited to such mechanical reactions as the recoil of a gun, the return of a bent spring, or the mutual attractions of the planets, but reaches down into other departments of science. To Newton himself, we owe the simple experiment in which he proved the extension of the principle to magnetic forces. He found the magnet to be drawn towards a piece of iron with a force precisely equal to that with which it drew the iron to itself. It was left to Newton's great contemporary, Robert Boyle, to demonstrate that the same law held good also for the force of electric attractions; an electrified body drawing a non-electrified one towards itself, and being itself attracted with an equal and oppositely directed force.

But Newton himself showed that there existed another and deeper meaning to the law of action and reaction, when he laid down the famous comment * which, though forgotten until unearthed by Sir William Thomson, virtually anticipated the nineteenth century discovery of the theory of the conservation of energy. As understood in the light of modern dynamics, any "action" in which energy is spent and work done is found to have its corresponding "reaction" in the possibility of the energy thus stored being at some later time set free. That particular "action" of an agent to which Newton told us there was still an equal "reaction," when the action was meas-

* "Si æstimetur agentis actio ex ejus vi et velocitate conjunctim," &c. Principia philosophiæ naturalis. This famous scholium is paraphrased as follows by Thompson and Tait ("Treatise on Nat Phil." Chap II., Art. 269):—"Work done on any system of bodies has its equivalent in work done against friction, molecular forces, or gravity, if there be no acceleration; but, if there be acceleration, part of the work is expended in overcoming the resistance to acceleration, and the kinetic energy developed is equivalent to the work so spent."

ured by the product of its momentum into its velocity, was, in fact, nothing other than its *capacity for doing work.*

If you lift a pound of iron to a certain height against the pull of gravitation, the action implies the expenditure of a certain amount of energy, the equivalent of the work done. Precisely an equal amount of work (saving a trifling proportion converted into unuseful work of another kind, namely heat) can the mass of iron do in falling back again; for by its fall it may do the work of raising another pound to the same height.

In the science of electricity and in magnetism the same fundmental principle holds goods. Suppose, for example, energy to be spent in the following action. Let a heavy weight descend over a pulley, and in its descent cause the disc of a Holtz's electric machine to rotate; the work done in this case is electric work, the energy being expended not in moving matter against gravitation or any similar force, but in moving electricity against those electric forces which are continually urging it to run down to the dead level of equal and uniform potential. But our supply of electricity thus provided can itself be made to do work, because it can thus run down and give out in another form the energy expended on it. Only let it be led by wires into the terminal poles of another Holtz machine, and it will drive it round, and by driving it round may be made to lift a weight. The reaction here is the converse of the action, and would be equal but for inevitable waste by friction and dissipation of the electric charges.

Another instance of electric action and reaction is afforded by the reversibility of dynamo-electric machines, such as that of Gramme, as mentioned at the outset. The Gramme machine can be used either as a generator or as a motor. If driven by the power of a steam engine or a gas engine, or by wind power or water power, or hand power—in short, by any mechanical means whatever—it generates powerful currents of electricity, which may be used for producing electric lights, or any other kind of work that an electric current can do; the currents of electricity being due to the rapid movements of coils of wire fixed upon a rotating armature across a field of magnetic force, excited by the currents themselves in the machine. If, on the other hand, currents furnished by any suitable source are led by wires into the coils of a Gramme machine, these currents will drive it round, and will expend their energy in producing mechanical rotation, enabling the machine to be used as a motor.

Here I may remark, in passing, that the reversibility of the Gramme machine affords a means of electric, or rather of electro-mechanical storage. Suppose we want to store electric currents. Set them to drive a Gramme machine, and let the Gramme machine, by means of a pulley, gradually wind up a very heavy weight. If, subsequently, we let the weight descend, it will drive the Gramme machine, and will generate currents as it runs down.

ACTION AND REACTION IN VOLTAIC CELLS.

We now pass to the more immediately important case of the reversibility of the voltaic cell, and of its chemical and electrical actions.

In the ordinary voltaic cells, currents of electricity are produced at the expense of a certain consumption of zinc and of acid. These materials may be regarded as the fuels of electric currents, just as coke and coal are the fuels of steam power. Like those fuels, they represent a store of energy. Everybody knows that when two bodies attract one another (as for instance the earth attracting a stone), and we do work in separating them, they posses the power of rushing together again, and of doing work; and, therefore, when so separated, may be said to represent a store of potential energy. This is equally true in the case where we do work against the atomic attractions known as chemical affinity. Zinc has a certain chemical affinity for oxygen. To separate an atom of zinc from one of oxygen requires energy to be expended. When thus separated they have the chance of doing work in reuniting, this work generally appearing in the form of heat. When a piece of coal is burned, that is to say, is permitted to unite chemically with oxygen, its store of energy runs down, and manifests itself in the evolution of heat. A piece of coal represents a store of energy. So does a bag of hydrogen gas. So does a piece of zinc;

for zinc can burn directly and give out heat; or may burn indirectly by being dissolved in sulphuric acid, also giving out heat. A Daniell's battery represents a store of energy. A pinch of gunpowder also represents a store of energy. The amounts differ, it is true; and the rate at which some of these stores can be made available for use, also differs widely in the different cases.

An ounce of coal represents an amount of energy which, if entirely expended in doing work, would raise 695,000 pounds one foot high against the force of gravity, or would do 695,000 foot-pounds of work. In an ounce of gunpowder is stored about 10,000 foot pounds of energy. An ounce of zinc represents a store of only 113,000 foot pounds. An ounce of copper represents a store of about 69,000 foot pounds only. An ounce of hydrogen gas will yield, by combining with oxygen, 2,925,000 foot pounds of work. Joule first showed us how to make use of facts like these, in calculating by its mechanical value the electric power of voltaic cells. Let us apply these considerations to the storage of energy in any ordinary voltaic cell—say, for example, the Daniell's cell used in telegraphy. In this cell we have certain liquids containing zinc and copper, chemically dissolved in sulphuric acid, and into these liquids dip a plate of zinc and a plate of copper. The zinc plate slowly dissolves away, and at the same time, metallic copper is gradually separated out of the solution, there being about $1\frac{1}{2}\frac{1}{6}$ ounce of zinc consumed for every ounce of copper deposited. Now, to separate an ounce of copper from its solution in sulphuric acid, requires 69,000 foot pounds of energy to be spent upon it; and as $1\frac{1}{2}\frac{1}{6}$ ounce of zinc represents a storage of 118,650 foot pounds, the consumption of this weight of zinc is enough to provide the 69,000 foot pounds needed to separate the copper, and to leave a surplus of 49,650 foot pounds. It is this surplus which goes to maintain electric currents in the circuit, and to do electric work.

But, as we have remarked, the voltaic cell is reversible. If we take such a cell, and by means of some superior electromotive force drive electric currents back through the cell, the whole action will be reversed. Copper will be dissolved, and zinc will be deposited. The copper in dissolving will help the process by giving part of the necessary energy, and our currents will thus once more give us back pure zinc, and so separating out the zinc we do work and actually store energy.

In modern treatises on heat, frequent reference is made to an ideal and wholly impossible sort of engine known as Carnot's reversible engine, which is supposed to have the power of being worked backwards, not however in the engineer's sense of reversing the motion, but in a much more striking sense. Carnot's engine, like every other engine, is supposed to act by heat passing through it from a boiler to a condenser, part of the heat so passing through being converted into work, and the ideal reversibility consists in the suggestion that if the engine could be driven backwards by spending mechanical power upon it, the work should be converted back into heat, and the heat should be pumped back from the condenser into the boiler, and from the boiler back into the fuel.

But while Carnot's reversible heat-engine exists in the ideal state, we have in the voltaic battery a real reversible engine; for it is possible here to pump back these electric currents into our cell, and even to go further, and to pump into its metallic state the zinc, the fuel which had been consumed in the cell.

Now, while we are thus using currents to separate the zinc from its solution, the zinc is all the while tending to reunite.

Its tendency so to reunite—its chemical affinity, so called—manifests itself as a counter-electromotive force; this counter-electromotive force being technically known to electricians under the name of "polarization." The name is not a happy one, but will do if we once understand its meaning. Polarization is the electric reaction at the poles or electrodes of a cell, and is of the nature of a counter-electromotive force. To send a current through a cell, we must apply an electromotive force at least as great as that to which the polarization can attain, or we shall not overcome the tendency of the separate elements to reunite. In fact, it is in overcoming this polarization force, that we do the work of storage. We do electro-chemical work by overcoming electro-chemical forces,

just as we do mechanical work by overcoming mechanical forces. In every case the storage is effected by overcoming some reaction. If weights that have been lifted, and springs that have been bent, and metals that have been chemically separated, and did not tend to return to their former condition, none of these could serve as vehicles or instruments for the storage of energy. Without reaction storage of energy would be impossible.

It will next be convenient to glance briefly at the principal laws affecting the counter-electromotive forces of polarization, that is to say, those electromotive forces which are developed by currents at the poles of the cells, and which tend to oppose a reaction to the currents that evoke them.

LAWS OF POLARIZATION.

To tear away an atom of any element from its compound with an atom of another element, requires the use of a definite amount of electricity, and necessitates further that this electricity should be urged forward with at least a certain minimum of electromotive force. Take for example the case of the decomposition of water by the electric current. To tear away a single gramme of hydrogen from the oxygen with which it is combined requires no less than 95,050 webers ("coulombs") to flow through. But these liberated and separated gases are in one sense a store of energy, and would, if allowed to combine together (by burning), produce heat. Their "affinity" for one another is very great, and the electric current has to do a considerable amount of work in tearing these two kinds of atoms away from one another. To see what this work amounts to, let us inquire how many units of heat they would evolve in burning. Careful measurements by Favre, Andrews, and Julius Thomsen, show that 34,000 calories of heat would result. Now, the work done to separate the gases is, of course, equal to the work they would do by rushing together. The affinity of the gases manifests itself as a reaction against the electromotive force of the current employed to separate them. This reaction is itself a counter electromotive force. When we overcome an opposing electromotive force by pushing a certain quantity of electricity from one point to another against its reaction, we do work just as truly as when we overcome an opposing mechanical force by pushing a certain lump of matter from one point to another against its resistance. In the particular case of the decomposition of water, the opposing electromotive force of polarization has a magnitude when expressed in the proper units of 1.49 volts. It is possible, when we know how much heat would be evolved by the combination of an equivalent of any substance with oxygen, to calculate the amount of the electromotive force that would have to be applied to tear away that substance from its combination with oxygen. Or, again, suppose we know that of two elements one will, when combining with its equivalent of oxygen, give out more heat than another, then we know that it has a greater affinity for oxygen, and, from the difference between their "heats of combination," we can calculate the surplus of electromotive force that we should have to apply to tear away one of these two from oxygen, and to put the other in its place.

In the accompanying table are given, firstly the equivalent heat values of the various metals when oxydized and dissolved in sulphuric acid. In the second column are given the electromotive forces that would be needful to tear away these elements from oxygen, or with which they tend to unite with oxygen—the value, in fact, of the electromotive force which measures electrically the chemical affinity of each of these elements for oxygen.

The order in which these metals are arranged is, in fact, nothing else than the order of oxidizability of the metals (in the presence of dilute sulphuric acid); for that metal tends most to oxidize which can, by oxidizing, give out the most energy. It also shows the order in which the metals stand in their power to replace one another (in a solution containing sulphuric acid). Thus, if copper be put into a solution of platinum the platinum is reduced, and some of the copper dissolves, evolving heat. If, however, zinc be placed in a liquid containing a copper compound, it displaces the copper, throwing down the latter as a metal and itself dissolving, while its surplus stored energy runs down as heat. In this order, too, the lowest on the lis-

TABLE OF 'ELECTRO-MOTIVE FORCE AS CALCULATED FROM THE HEAT OF OXIDATION OF THE CHEMICAL EQUIVALENT (H=1 GRAM)
AND AS OBSERVED BY DIRECT EXPERIMENT

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Name of substance.	Heat value.	E. M. F.	Electro-motive force observed in dilute sulphuric acid				
	Calories.	Volts.	With oxygen.	With platinum.	With ozone.	With peroxide of lead.	With zinc.
Potassium	69,800	3.04	..	3.17 (Bf.) 2.484 (Wh.)	..	3.528 (Wh.)	−1.144 (Wh.)
Sodium	67,800	2.95	..	..	..	..	..
Zinc	42,700	1.862	1.873	1.546 (Po.) 1 439 (Wh.) 1.67 (Bz.) 0.637 (R.)	..	2.448 (Wh.) 2.98 (J.)	0
Iron	34,120	1.570	..	..	..	..	[0.600 (A. & P.)]
Hydrogen	34,100	1.493	? 1.64 (Ta.)	0.86 (R.) 0.877 (Bz.)	1.9 (R.) 2.1 (Wh. Po. Sv.) 2 3 (Bf. Ta.) 2.265 (Ba. Bz.)	? 2.78 (Pl.)	..
Lead	25,100	1.133	..	..	..	2.38 (Pl.)	0.21 (A. & P.) 0.55 (D.L.R.)
Copper	18,760	0.818	0.74 (R.)	0.550 (R.)	..	..	0.953 (Po.) 1.079 (L. C.) .978 (L. C.) [0.75 (A. & P.)]
Silver	? 9,000	..	..	..	..	..	..
Platinum	7,500	0.327	..	0	1.21 (R.) 1.04 (R.)	0.6 (R.) 0.75 (R.) 0.90 (Wh.)	1.546 (Po.) 1.439 (Wh.) 1.67 (Bz.) [0.981 (A. & P.]
Carbon	? 2,000	..	..	..	1.435 (L. Swj.) 1.18 (R)	..	[1.096 (A. & P.)]
Oxygen	0	0	0	..	..	..	..
Nitric peroxide	−6,000	−0.29	..	..	..	..	1.97 (Bf.) 1.95 (L. C.) 1.96 (Sb.)
Chromic peroxide	−7,195	−0.31	..	..	..	..	2.028 (Sb.)
Manganese peroxide	..	..	..	−0.54 (Wh.) −1.101 (R.) −0.128 (R.) −0.404	..	0.504 (Wh.) 0.426 (J.)	1.944 (Wh.) 2.55 (J.)
Lead peroxide	..	..	..	−0.6 (R.) −0.75 (R.) −0.90 (Wh.)	..	0	2.448 (Wh.) 2.98 (J.) 2.1 (D'A.)
Silver peroxide	..	..	..	−0.7 (R.) −0.86 (R.)	..	..	..
Hydrogen peroxide	−10,800	..	..	..	..	..	..
Ozone	−14,800	−0.645	..	−1.04 (R.) −1.21 (R.)	0	..	..

D'A., D'Arsonval; Ba., Bartholi; Bf., Buff; Bz., Beetz; L. C., Latimer Clark; D.L.R., De la Rue; J., Joule; L., Lenz; Ll., Lloyd; Lo., Loggerecio; R., Raoult; Sb., Sabine; Sv., Svanberg; Swj., Saweljew; Ta., Tait; Wb., Wiedemann; A. & P., Ayrton and Perry (whose electrodes, long piece with an electrometer for contact in air, are placed in square brackets, as not being, like the rest, electrodes on the electro-motive force in sulphuric acid.

first, are the metals deposited by an electric current from solutions containing two or more of them: for that metal comes down first which requires the least expenditure of energy to separate it from the elements with which it was combined.*

REACTION OF PEROXIDES.

In the preceding discussion, oxygen has been taken as the standard electro-negative substance. But in point of fact there are substances more highly electro-negative; that is to say, substances which when made to combine with a metal such as zinc would give out together a larger amount of heat than zinc does with oxygen. Chief amongst those substances are chlorine and the haloids, the peroxides of the metals manganese, lead, and silver; such peroxidized bodies as chromic, perchloric, and permanganic acids, the peroxide of hydrogen, and ozone. If, for example, zinc be caused to combine with an equivalent of peroxide of lead, more heat is evolved than by the mere oxidation of zinc by free oxygen gas. It is clear then that in the unstable chemical aggregation of the peroxide we have a store of energy which can be utilized in giving us voltaic cells of still higher electromotive force. The highly electro-negative (or oxidizing) property of the brown peroxide of lead was discovered in 1835 by Munck af Rosenschöld, who describes it as being the most highly electro-negative substance known, being superior even to the peroxide of manganese which Volta found so highly electro-negative. There are, as a matter of fact, several oxides of lead, containing least oxygen of all these oxides; *minium* or red lead, containing a greater proportion; and the *brown* peroxide, with the highest proportion of oxygen, the best conductor and the most highly electro-negative of them. The peroxide of silver is still more highly electro-negative. This power can easily be verified by making a small voltaic cell with a pair of plates, the one platinum covered with a film of peroxide of lead, the other of zinc. One such cell will decompose water, which a copper-zinc pair will fail to do. For to do this requires, as may be seen by the table, an electromotive force exceeding 1.493 volts, this being the measure of the affinity of hydrogen for oxygen. The platinum-zinc pair would have an electromotive force of only 1.044 volts, while that of a peroxide of lead-zinc pair is about 2½ volts.

MINIMUM ELECTROMOTIVE FORCE FOR CHARGING.

The electromotive force of polarization in a cell, evoked there by the passage of a primary current through it, will depend upon what circumstances are produced at the two electrodes by the passage of the current. In the case of all ordinary liquids and metallic solutions, the products are known.

For each electrolyte there is a minimum electromotive force, without which complete decomposition cannot occur. For water, for example, this minimum is 1.495 volts. If the current be of less electromotive force than this minimum, the action may begin, but the charging current will be stopped the moment the opposing electromotive force of polarization has risen to an equal amount. It is for this reason that in charging a Planté cell, or a Faure cell, we must use at least two cells of Grove's or Bunsen's battery, or at least three cells of Daniell's battery.

The chemical work that is done in any

* The calculation of the figures in the second column (the electromotive forces from those of the first column the number of the calories of heat evolved by the oxidation and solution of that amount of the substance that is chemically equivalent to one gramme of hydrogen) is effected in a manner originally suggested by Mr. Joule and Sir William Thomson. The number of heat units or calories is ascertained by direct experiment in the calorimeter in the manner familiar in the researches made on heat of combination by Favre, Andrews, Julius Thomsen, and Berthelot. Now, Faraday showed that the quantities of metals concerned in the electro-chemical operations in voltaic and electrolytic cells are proportional to their chemical equivalents; and the later researches of Weber, Kohlrausch, Mascart, and Alder Wright have shown that this proportionality can be expressed by a numerical coefficient, which we may call the "Faraday coefficient," and which will depend on the unit in which electrical qualities are expressed. If we take the coulomb (or "weber," as the unit of electric quantity, then the Faraday coefficient is 0.000105; or, in other words, each weber (or coulomb) of electricity which passes through a cell will involve the liberation or combination of 0.000105 grammes of that element, whose chemical equivalent is 1, and proportionally more of those whose chemical equivalents are greater. The heat value of the chemical work done by one weber (or coulomb) of electricity, in removing or depositing any metal in any cell, is obtained by multiplying by 0.000105, the figure standing opposite the metal in question, in the first column of the table. These heat values are turned into absolute units of work by multiplying by Joule's mechanical equivalent of heat, which is, in the centimetre-gramme second system of units, equal to 41,530,000, or 41.53×10^6. But the work done in moving a unit of electricity against the reaction in a cell measures the power of that cell to react electrically, or, in other words, measures its electromotive force relatively to oxygen, which is taken here as the standard electro-negative substance. These electromotive forces will be expressed in terms of the appropriate of electromotive force, the volt.

secondary battery, or electrolytic cell, is proportional to the strength of the charging currents, to the time it lasts, and to the effective minimum electromotive force of polarization in the cell itself. It is not increased by increasing the electromotive force of the charging current much beyond this value; for though a higher counter-electromotive force may be temporarily called out, the work done against this added opposition is wasted in local heat, which is detrimental to the power of the cell. The cells should be charged with only just sufficient electromotive force to overcome their reaction. To charge a Planté cell, two Bunsen cells—not twenty—should be used. The storage will be slower, it is true, but it will be more economical by far.

STORAGE POWER LESSENED BY HEAT.

Heat diminishes the counter-electromotive force of the cells during charging; it therefore diminishes the amount of chemical work done in charging them, and diminishes the amount of charge thereby stored. Secondary batteries should be kept as cool as possible during charging. A simple experiment in proof of the diminution of polarization by rise of temperature is the following. Let a single Grove's cell be connected with a water-voltameter: no gases are evolved until the voltameter is heated to near boiling, when the gases come off freely. Bartoli examined the electromotive force of polarization in a cell containing sulphuric acid with electrodes of platinum, and found it to be twice as great when the liquid was at 5° C as when raised to its boiling point. Beetz and Robinson have independently investigated the same effect, and their results agree precisely. Beetz found the polarization 2.216 volts at the ordinary temperature of 20° C, and as the temperature was raised it fell off; gently at first, more rapidly afterwards, till at 100° C. it was only 1.904 volts.

Temperature.	E.M.F. (Beetz).	E.M.F. (Robinson).
16° C.	2.216	
20°		2.216
30°		2.194
43°		2.148
53°		2.105
57.5°	2.101	
60°		2.095
80°		2.040
94°	1.960	
100°		1.904

IMPORTANCE OF SUFFICIENT CURRENT DENSITY.

The influence of the polarization force of a cell of the size of the plates used as electrodes relatively to the strength of the charging current has also been investigated by several experimenters, amongst them Crova, Poggendorff, and Bunsen, and more recently by Bartoli and Blondlot. It is found that the degree to which a counter-electromotive force or polarization force is set up depends very greatly on the quantity of current per unit of surface of the electrodes employed. If the current be weak, and the electrodes large, the polarization never reaches its maximum. On the other hand, if the electrodes be very small surface, and the current a strong one, the polarization may attain abnormally high values. Thus Buff, electrolyzing water with small platinum points, found the counter-electromotive force to be no less than 3.57 volts. The difference between this and the minimum value of about 1.493 must be accounted for by the fact that the state of the liberated products varies with the condition of liberation. With greater "current density"* the gases liberated by decomposing water are no longer simple oxygen and simple hydrogen. With greater current density, a greater proportion of the oxygen comes off in the more highly electro-negative condition of ozone, and more peroxide of hydrogen forms also round the anode, whilst at the kathode, the hydrogen which is evolved possesses in unusual degree the active properties attributed by chemists to "nascent" hydrogen" that is to say, a larger proportion of it probably is, at the moment of liberation, in some abnormal allotropic condition, bearing the same kind of relation to ordinary hydrogen as ozone bears to oxygen. The allotropic hydrogen is more oxidizable; the ozone more ready to oxidize. Their union would evolve more heat than the union of equal weights of ordinary hydrogen and ordinary oxygen. It requires greater electromotive force to keep them apart; their own tendency to unite is greater. J. Thomsen

* This term means "the amount of current per unit of surface of the electrodes," and is calculated for either electrode (in the simple case of parallel plates), by dividing the total strength of the current in webers (*amperes*) by the area of that electrode in square centimeters.

has even measured the heat value of ozone as compared with oxygen, and it takes its place in our table of elements at the bottom, below the peroxides, though chlorine and the haloids would be still lower on the list if they came within the scope of present considerations.

It follows from the above argument, that if we wish to make our storing cells exert their highest possible reaction, we must store them, using a current whose strength (or quantity) is proportioned to the size of the cell. If we use too weak a current, the maximum polarization, and therefore the maximum efficiency, will never be attained. This is one of the rocks on which amateur constructors of storage batteries have come to grief. The current density* is a most important consideration, especially in the early stages of the formation of the cells. It certainly should not be less than 50 milliwebers per square centimeter of surface in the cell.

EFFECT OF STATE OF SURFACE.

Again, the state of the surface of the electrodes has much to do in determining the state in which the gases are liberated, and the resulting polarization force. Svanberg, in electrolyzing water with copper electrodes, found the polarization to be .72 volts with smooth plates, and only .47 with corrugated plates. Poggendorff, using platinum plates, found the maximum polarization to be—with bright surfaces, from 2.28 to 2.50 volts; while with surfaces platinized, *i.e.*, coated with a black, powdery deposit of platinum, the polarization in cells, like those of Planté and Faure, where the original surfaces of the plates of lead are coated with thick films of peroxide, or of reduced metal, these considerations do not apply, except for the first operation of charging. Indeed, I have found, experimentally, that there is a gain in scratching the leaden surfaces before forming the coating of peroxide; the coating is more adherent, and the effective surface somewhat greater; advantages beside which the greater preliminary waste of liberated gases on first charging is comparatively trivial.

We will next take a brief historical glance at the various stages in the invention and perfection of accumulators or storage batteries.

HISTORICAL SUMMARY.

Within one year after the discovery of the pile by Volta, two very important observations had been made. Nicholson and Carlisle, in 1800, discovered that the current so produced could decompose water;* and in 1801 Gautherot discovered that the wires of platinum or of silver which had been employed to thus decompose salt water acquired, and retained after being detached from the pile, the power of yielding a transient current, as could be proved by their efficacy in causing muscular contractions in a frog's leg, and in yielding the so-called galvanic taste. This is the phenomenon afterwards denominated "the polarization of the electrodes." It was found to consist in a peculiar state of the electrodes which manifested its presence, even before the exciting current of the pile was cut off, by producing an enfeebling reaction against that current, the polarization current being in a direction which opposed the exciting current. The phenomenon is well known to all electricians, and occurs not only in electrolytic cells, but in the cells of the voltaic batteries, where the liberation of hydrogen bubbles is accompanied by an opposing reaction of the same kind. Indeed, the difficulty with batteries has been to get rid of the polarization.

In 1803, Ritter, of Jena, reobserved the same phenomenon, using wires of gold; and perceiving the importance of this reaction, he constructed a secondary pile which we will presently describe.

The phenomena of the secondary currents due to polarization were further investigated by Volta, Marianini, Davy, Grotthuss, De la Rive, Sinsteden, Becquerel, Schœnbein, Matteucci, Grove, Faraday, Buff, Beetz, and others. Mat-

* Crova, and more recently Bartoli, have given exact formulæ, by which to express this important relation. Let P represent the E.M.F. of polarization at any time: it can be expressed as a function of the possible maximum polarization and of the density of the current. Let A be this possible maximum E.M.F.; s = the surface (supposed uniform), q the time t (supposed short), then

$$P = A\left(1 - 10^{-a\frac{q}{s}}\right)$$

where a is a constant (8,400 circ). This may be interpreted as follows: The polarization falls short of its possible maximum by an amount the logarithm of which is inversely proportional to the current density.

* Water had been previously decomposed by discharges from an electric machine in 1789, by Paetz van Troostwyk and John Cuthbertson.

teucci and Grove in particular studied the reaction currents set up by the presence of uncombined gases at the electrodes, and the latter constructed a well-known "gas battery." In 1869, M. Gaston Planté brought out a secondary battery constructed of lead plates dipping into sulphuric acid, and in a remarkable and valuable series of classical researches, he investigated the phenomena of their action. More recently, modifications of the Planté accumulator have been suggested by M. Camille Faure and M. A. de Méritens. These various systems will be described in detail presently. Professors E. J. Houston and Elihu Thomson, of Philadelphia, have made the suggestion which embodies the principle of reversibility in the case of the Daniell's cell. They place two horizontal copper plates in a cell containing sulphate of zinc in strong solution. To change this cell a current is sent through it from the top plate downwards. The upper plate or anode dissolves, forming a solution of sulphate of copper, which, being specifically lighter, floats on the sulphate of zinc. On the lower plate, metallic zinc is deposited; so that, when charged, this battery is merely a "gravitation Daniell" battery. It will afterwards yield a current so long as there remains any zinc in the metallic state, or so long as there exists a chemical difference between the two electrodes. This suggestion has been modified by M. d'Arsonval, who uses an electrode of lead, or of carbon covered with leaden shot along with an electrode of zinc in sulphate of zinc. In this case, when the cell is charged, zinc is deposited upon the zinc plate, while the lead becomes peroxidized.

Other suggestions have come still more recently from M. J. Rousse, who proposes the use of ferro-manganese, and of palladium as electrodes. The advantages offered by the former alloy over zinc do not appear to be great; and the cost of the latter metal is so enormous as to render suggestion valueless for practical ends.

RITTER'S SECONDARY PILE.

Ritter discovered the possibility of secondary voltaic action while studying the chemical action of electric currents upon liquids. He employed a large voltaic pile as his source of electricity, and observed, not only the decomposition of water into oxygen and hydrogen, but the phenomena of formation of peroxides, and of the deposition of metallic films at the anode and kathode respectively, when metallic solutions were employed. He found that his gold wires, after becoming covered respectively with film, if separated, oxygen and hydrogen could set up violent contractions in a frog's leg. He further investigated the phenomenon with different kinds of wires, and found platinum to yield the best result: gold coming next in order, then silver, copper, and bismuth. With lead, zinc, and tin, however, he obtained no result. He further showed that even after having been removed from the water and dried, the pair of gold wires retained their activity, and when afterwards plunged into water yielded a current in a direction opposed to that of the pile, by which they were originally rendered active.

One remarkable experiment of Ritter's found its way into English journals. Ritter took a *louis d'or*, and placing moistened cloth against its two sides, proceeded to pass through this combination a current from a powerful pile. The coin still laid in its wrappings was afterwards found capable of furnishing a current. This led Ritter to propound the view that conductors of electricity, such as the metals, could be charged with electricity; the coin between its metal wrappings being, according to him, the analogon of the Leyden jar lying between its two coatings of tinfoil. He mentions also mercury, carbon, graphite, and bin-oxide of manganese, as being capable of receiving galvanic charges. "Each of these bodies," he says, "becomes charged upon both its sides, just like the glass of the Leyden jar, and this state of charge, when it exists in such concentration or intensity, as in the foregoing bodies, is perceived as a state of oxygenation on one side, and a state of hydrogenization on the other." He also draws attention to the curious behavior of quicksilver, which, when placed between water and water and included in the circuit of a voltaic pile, shows movements due to changes in surface tension where the films of gas are produced. Ritter advanced to the rather unwarranted conclusion that, since in these cases the charge stored up depended on the press-

ure of oxygen and hydrogen films produced from the water, there must necessarily be water in all bodies, and that chemical separation always accompanied electric charge.

To produce these effects of galvanic charge upon a larger scale, Ritter constructed a secondary pile (*Ladungs-Saule*),consisting of a series of discs, of one metal—copper—separated by pads of cloth, moistened with a solution of salt, or sal ammoniac. When charged from a voltaic pile of ordinary construction, this secondary pile received a charge, which afterwards enabled it to give a shock to a person touching its two ends with his hands. It would also decompose water, and, in short, reproduce all the effects of the primary pile, but reversed as to the direction of the currents it furnished.

Ritter was not happy, however, in all his efforts to explain what he observed. He founded his arguments on the incorrect supposition that oxygen consisted of water, combined with negative electricity. It was some years before the researches of Volta, Marianini, and Schonbein, placed the phenomena on their true basis; Schonbein adding the very valuable observation that the presence of ozone in the liberated oxygen intensified the secondary electric action.

PROGRESS IN ELECTRO-CHEMICAL KNOWLEDGE.

The researches of Davy, De la Rive, and of Faraday, upon the chemical phenomena of the voltaic cell, showed that the chemical decompositions within the battery were amenable to the same laws as those which took place in an electrolytic cell at a distant point of the circuit. Faraday brought out several most valuable points in his "Experimental Researches." He describes (Art. 750) how, in electrolyzing acetate of lead, "in place of oxygen, or even the gases already described, peroxide of lead now appears at the positive,* and lead itself at the negative pole." In his argument for the chemical theory of the cell, he remarks that while those substances are highly electro-negative, which cannot be oxidized, there is another class of substances still more highly electro-negative, namely, those substances which readily give up oxygen, the peroxide of manganese being more negative than platinum, as Volta showed, and the peroxide of lead being still more negative than that of manganese, as Munck af Rosenchöld had shown. Faraday remarked (Art. 1822) on the good conducting power of the peroxide of lead. He also observed that red lead is more negative than platinum. De la Rive indeed utilized the strong electro-negative property of peroxide of lead in the construction of a cell in which this substance, packed in a porous pot around a platinum strip, served as one pole, zinc being the other. Niaudet, in his treatise on the "Pile Electrique" (published 1878), suggests that red lead (minium) would have answered equally well. In the Bakerian lecture for 1843, Wheatstone announced that he had measured the electromotive force of peroxide of lead against zinc, and had found it to be 2.266 of that of a Daniell's cell (=2.448 volts).

GROVE'S GAS BATTERY.

In 1842, Sir William (then Professor) Grove described the well known gas battery, which was indeed nothing else than a reversible oxygen and hydrogen battery, in which work had first to be done to produce chemical decomposition, electric currents being passed through acidulated water from one platinum pole to another, these currents being of sufficient power to overcome the opposing mutual affininity of the constituent gases, the reaction of these separated gases tending to produce a counter current of considerable power, and manifesting a so-called electromotive force of polarization.

The rationale of the gas battery is simple enough, provided it be once understood that platinum possesses a power, almost unique amongst the metals, of absorbing upon its surface both oxygen and hydrogen gas. When a current is passed between platinum electrodes in acidulated water, the two gases not only rise in bubbles, but form a film at or in the surface of the metal, which

* Professor Adams, commenting on this observation of Faraday's, shows that Faraday thus anticipated Planté in the discovery of the leaden cell. But a Planté cell filled with acetate of lead is almost useless. The fact that peroxides are thus deposited on the anode was thus discovered before Faraday's researches by Nobili, who noticed also the beautiful irridescent colors in the rings of peroxide films deposited on an anode plate opposite a printed kathrode; the phenomenon known usually as *Nobili's rings*.

when so charged behaves differently from neutral clean platinum. The hodrogenized film resembles zinc or some oxidizable metal, and exercises toward clear platinum, and *a fortiori* toward oxygenized platinum, a strong electromotive force. The energy spent by the decomposing current in separating these gases is stored in the gases that are thus separated. In their subsequent reunion, the energy of their separation runs down into some other form; into heat if the gases are merely mixed and exploded together; into the energy of electric currents if the gases are suffered to recombine through the liquid, by the slower and cooler process of slow chemical combination in the cell.

With a gas battery of 50 pairs, Grove produced electric lights, effected various chemical decompositions, and produced shocks which could be felt by five persons joining hands.

PLANTE'S SECONDARY BATTERIES.

M. Gaston Planté, to whom, more than to any other experimenter, the recent advances in the practical construction of storage batteries are due, very carefully re-examined the whole question of the polarization of electrodes, using different metals as electrodes, and different liquids as electrolytes, and found that the greatest effective polarization was produced when dilute sulphuric acid was electroized between electrodes of lead. Similar researches, though less complete, had been made before by Sinsteden, Poggendorff, Daniell, Lenz, and Saweljew, and by Edmond Becquerel. Sinsteden had even obtained from leaden electrodes polarization currents of sufficient power to raise a thin wire to incandescence. These researches had mostly been undertaken with the view of ascertaining the cause why the currents furnished by most of the voltaic combinations then in use fell off so rapidly in strength. The result of these researches was to suggest methods of getting rid of the residual polarization and its tendency to set up an opposing counter current.

M. Planté, however, struck out in an opposite course, and endeavored instead to find the best means of provoking the phenomenon of polarization, in order, as he expressed it, to turn to profit the secondary currents and to accumulate the energy of the battery. He was, therefore, led by his preliminary researches in 1860 to construct a secondary battery consisting of nine cells, in each of which two long and wide strips of lead, separated by coarse cloth, were rolled together in a spiral form, and immersed in dilute sulphuric acid. A few months later he modified this form by placing side by side in a rectangular box two series of lead plates, alternately connected together, each plate being about eight inches long and nine inches high. He recurred afterwards to the spiral form as being more convenient, but replacing the coarse cloth by narrow strips of gutta percha.

But the cells thus constructed were not ready for immediate action. Two clean lead plates give no current of their own; they are only intended to receive and store up what is sent into them from some external source. And at first, while the lead is bright, when a current is sent through the cell from some suitable source, such as three or four Grove's or Bunsen cells, the separated oxygen and hydrogen gases bubble up to the surface, for the most part, leaving only a very small percentage as an adherent film, and, in consequence, yielding only very transient secondary currents. The plate of lead by which the current enters is, however, attacked by the oxygen, and becomes covered by a thin layer of brown peroxide of lead, and this film, though thin, is powerfully electro negative toward metallic lead, and toward the film of hydrogen on the kathode plate. The cell in this condition will therefore produce a current, and in so doing, the peroxide is partially reduced to the metallic condition, and assumes in its reduction a spongy or loosely crystalline texture. If now the cell be again charged, and charged in the opposite direction, the other plate of lead becomes, in like manner, peroxidized, while the hydrogen bubbles are less freely evolved, for the atoms of gas unite as fast as they are liberated, with the oxygen of the peroxide, and reduce it to the metallic condition. Every time the charging current is thus reversed the films of peroxide, or of spongy metal, become thicker, until the lead to a considerable depth is bitten into. And

every such operation increases, therefore, the power of the cell to store up in this electro-chemical fashion the energy of the currents sent into it. M. Planté, who minutely describes the process of "forming" the cell, compares it to a sort of electro-chemical *tanning*. The first day, the alternate charging should be done at intervals of a quarter to half an hour, the cell being discharged between each operation. The next day, the duration of the alternate charges may be increased from a quarter of an hour to a whole hour; the day after to two hours. After repose for a week or a fortnight the charges may last several hours; and by the end of several months, the cell will be well "formed;" after which it should, when used, be charged in one direction only, otherwise, the whole thickness of the lead plates will be bitten into and transformed into peroxide.

The electromotive force thus developed in a fully charged Planté cell may be as much as 2.38 or even 2.7 volts; and as the large area and close proximity of the plates diminish the resistance of the liquid to a very small quantity, such cells are capable of furnishing a very powerful current* for a few minutes, and their calorific power is considerable. In fact, they discharge themselves too well, and run down too soon for many purposes. A single cell 10 inches high will, however, suffice to keep a platinum fire, 2 inches in length and $\frac{1}{100}$ inch in diameter, glowing at a bright red heat for three quarters of an hour. The amount of charge will, of course, depend on the size of the plates and on the degree to which the process of "formation" has been carried out. It may be charged by using two or three Grove's or Bunsen's cells, or by the current of a dynamo-electric machine. A single Grove's or Bunsen's cell will partially charge a Planté accumulator, but cannot raise it to its full power, because the electromotive force of such a source is only 1.9 volts, or less than that of the cell at full power. The cells, when in good condition, will retain their charges for many days, though there is a gradual decay in the charge, owing probably to internal electrolytic convection in the liquid. During discharge the current is evolved with great constancy until quite near to the end of the operation, when there is a sudden falling off. This effect is very remarkable, and arises probably from the conditions of internal resistance, both in the peroxide films, and in the liquids. A Bunsen battery of small size and considerable internal resistance will take some hours to charge a cell fully; while a dynamo-electric machine may fully charge it in half an hour; but the rate of discharge will be alike in each case. The secondary battery plays, therefore, a controlling part in the rate at which such actions may go on. I am inclined to think that the well-known action of a damp string in retarding sparks of a Leyden jar, is due to a similar kind of action. Another curious fact concerning Planté's accumulator is that, after having been rapidly discharged, and left to itself, it will presently yield a small residual current; a phenomenon strikingly similar to that of the residual spark in the Leyden jar. In consequence partly of these useless residual charges, and partly also because a fraction of the energy of the charging current is wasted in heat in the cell, there is a loss of about 11 or 12 per cent. between charging and discharging. M. Planté states that voltametric measurements show that of the whole current 88 to 89 per cent. is given back by the cell. According to M. Géraldy a Planté cell containing 1.445 kilogrammes of lead can store 4.983 kilogrammeters of energy, being at the rate of 3.45 kilogrammeters per kilogramme, or 11.329 foot-pounds per pound.

M. Planté has devoted much attention to the effects produced by uniting these secondary cells when charged, in series, so as to augment their effects. By grouping them in a box with a Muller's commutator above them he is able to charge them in parallel arc, and discharge them in series. Twenty cells will thus furnish for a few minutes an electric arc light. With a large battery of 800 cells thus arranged, M. Planté has carried out a number of fine experiments of the highest theoretical and speculative interest, and destined some day to bear fruit in practical applications. He has further devised an instrument, known as a "Rheostatic Machine," consisting of a number of mica condensers connected with a rotating commutator, by which they can

* The E.M.F. being 2.38 volts, and the resistance as small as from 0.12 to 0.048 ohm, the current through a short stout wire may be considerably over 20 webers (*amperes.*)

be charged in parallel arc, and discharged in series, which, when supplied by the large battery of 800 cells, yields sparks 12 or 14 inches in length, and produces effects which otherwise can only be produced by statical (frictional) electric machines, or by the use of the induction coil. He has observed, amongst a host of other wonderful things, a very remarkable case of globular discharge, the exact counterpart on a small scale of the much disputed phenomenon of globular lighting.

APPLICATIONS OF PLANTE'S ACCUMULATOR.

Since 1872, the Planté cell has been regularly used for the operations of cautery. M. Trouvé, the well-known maker of electrical instruments in Paris, has brought out a whole series of little surgical appliances adapted for use with the Planté cell, including little incandescent lamps to illuminate the cavities of the body—as for example to aid the surgeon in operation upon the larynx—and dentists' appliances for destroying the nerves in hollow teeth. By the kindness of Professor W. F. Barrett, of Dublin, I am enabled to exhibit one of these medical cells, and the various appliances of galvano-cautery adapted for use with the same. The advantage of employing a secondary cell for such a purpose, is that such cells may be made of a higher electromotive force, and of a smaller resistance than any single cell of any primary battery yet invented.

Mr. Planté, in 1860, suggested that his accumulators might be usefully employed in telegraphy, instead of the voltameters with platinum electrodes as Jacobi proposed, in order to obviate the retardation in the transmission of signals, caused partly by induction and partly by the residual magnetism of the electro-magnets of the instruments. The opposing current set up in the secondary battery which is in the circuit, being in the contrary direction, sweeps out the residual magnetism and the residual static change so soon as the working battery is cut out of the circuit.

Another application brought out by M. Planté is to the purpose of obtaining a household light, which will serve instead of a match box when it is desired to light a candle or a jet of gas. The "Briquet de Saturne," as he has whimsically termed this new fashioned tinder box, is merely a small accumulator charged by four little Daniell's cells, and provided with a "push," that, when pressed, completes the circuit, through a small strip of platinum foil, which glows with a red heat.

At the suggestion of M. Achard, Planté's accumulators have been employed to actuate a brake on a railway train. To work a brake a great power is required for a short time. This can be done by employing large electro-magnets to move the mechanism of the brakes, the electro-magnets being excited by six Planté cells which distribute power to a dozen different brakes. As the charge stored would last but ten days, six Daniell's cells are also added to provide a constant, though feeble, source of current to keep the accumulators charged, and during the instant when the brakes are put on, the six Daniell's add their feeble share to the total effect. More recently M. Trouvé has employed a battery of six Planté accumulators, to propel a tricycle through the streets of Paris, attaining a speed of about 10 miles per hour. The comparative lightness of the cell in proportion to the mechanical power it can evoke in a small electro-magnetic motor, giving a great advantage in this case over a small steam engine. Trouvé has also fitted a small pleasure boat, with a similar apparatus. If very thin laminæ of lead—lead foil in fact—be employed to form the cells, still greater lightness may be attained in proportion to accumulating power, though, probably, at the expense of durability. This possibility has tempted M. Gaston Tissandier to propose to steer, or even propel, balloons or other aeronautical vehicles by electrical means.

M. Niaudet has shown how the Planté accumulator may be utilized in naval signaling. His suggestion is to exhibit flashing electric lights of great brilliancy, but of short duration; the source being a series of accumulators which, during the intervals of darkness are being steadily replenished by a constant battery, or by the currents from dynamo-electric machines. There seems, indeed, no reason why a complete system of signals should not be arranged for ships on the principle of the system of flashing lights, suggested by Sir William Thom-

son for lighthouses. And there can be no question that were such a system adopted, many collisions at sea might be saved.

Yet another advantage of the system of accumulation, as carried out by M. Planté in his ingenious grouping of the cells, with the rotating commutator described above, is that with only two Bunsen cells as a source of currents, a powerful electric light can be maintained for a short time. For colleges and schools, and scientific lectures, when an occasional flash of electric arc light is wanted for some temporary purpose, without incurring the labor and expense of setting up 50 Grove cells every time, an accumulating battery is of great value.

APPLICATION TO PHOTOGRAPHY.

I would also draw attention to the great value which such an arrangement offers to photographers, who may desire to have at hand a source of brilliant and white light, with small expenditure of capital and of daily labor.

I mention these applications before dealing with more recent forms of accumulator, because there appears to be an amount of ignorance in the scientific world that is simply inexplicable, with respect to the magnificent researches carried on by Planté through more than twenty years, and the variety of useful applications to which his accumulator had been put before even the fame of more recent inventions had been noised abroad—before they had even been made at all.

We now pass to some of the recent modifications of the Planté accumulator, the principal amongst them being those of M. Faure and of M. de Méritens.

FAURE'S ACCUMULATOR.

In 1880, M. Camille Faure conceived the idea of constructing a secondary battery, in which, though the tedious process of "formation" by Planté's process is modified and shortened, the ultimate result is the same, namely, to produce upon lead plates, immersed in dilute sulphuric acid, a coating of peroxide of lead, that can readily be reduced to the loosely crystalline metallic condition. This, M. Faure accomplishes by the device of giving to his leaden plates a preliminary coating of red lead (minium), made up into a paste with dilute acid, and painted upon the surface. At first he adopted the spiral form of cell, the two plates being separated by felt or leather. More recently the rectangular form has been reverted to. The present mode of construction is as follows:—Eleven sheets of lead of such thickness as to weigh about 2 lbs. to the square foot are cut to the size of 12 inches by 10 inches, an ear piece being burned on at one corner. Or six sheets are taken; five of them being twice the above size, and folded double. These are painted thickly with red lead on both sides, and against each side is pressed a piece of felt, the face of which is also thickly coated with red lead; there being about 17 lbs. of lead and 25 lbs. of red lead altogether. These sheets are placed side by side in a water-tight case, alternate sheets being connected together by the projecting flaps. The cell is filled up with dilute acid; the total weight being about 50 lbs. When thus prepared, the cells are "formed" by a process of charging by means of the current of a dynamo-electric machine, the current being sent through them for six or seven days without intermission before they are ready for use. The red lead is reduced gradually on one side to the metallic state, and on the other assumes the condition of peroxide; but the cell does not attain its best condition for some weeks. As it is important that the electromotive force of the charging current should no much exceed that of the cells (2.38 volts), it is usual to charge a number of cells in series. The internal resistance of such cells is stated as being less than .01 ohm. The advantage of this system of construction is not confined to the saving in time of formation; there is the further advantage of thus obtaining a much thicker film of the working substance than in the Planté accumulator; though with the difference that the deposit of peroxide is not so regular in its structure. According to Sir William Thomson, a single cell of the spiral form weighing 75 kilogrammes (165 lbs.) can store 2,000,000 foot pounds of energy, or one horse power for one hour. Their action is more economical, however, when the charge is not drawn upon at this rapid rate. Economy in working is found to accompany slow and regular

discharge. Five or six hours is a more economical time for discharge, and then the waste is believed not to amount to more than ten per cent. Sir William Thompson states, that the probable loss of energy in charging is 10 per cent., and in discharging 15 per cent.; but he thinks it will be advisable in practice to be satisfied with less perfect economy than this. According to Reynier, a Faure cell, containing 56 kilogrammes of lead, can store 210,000 kilogrammeters of electro-chemical energy; or at the rate of 3.75 kilogrammeters per kilogramme of lead, or 12.85 foot pounds per pound of lead. According to M. Géraldy, the figure is slightly less, being only 3.28 kilogrammeters per kilogramme, or 10.76 foot pounds per lb. Such a cell, when on short circuit can, I am informed, furnish for ten hours a current of 10 to 14 webers continuously.

M. Faure is now constructing larger cells, of which, by the kindness of Major Ricarde-Seaver, I am enabled to give the following details:—The leaden plates are about 17 inches long by 12½ wide. About 50 pounds of red lead are used; and the sixteen sheets of lead themselves weigh about 20 pounds. The sheets which are to serve as positive electrodes are eight hundredths of an inch thick; those which are to serve as negative electrodes are four hundredths of an inch thick. After being painted with red lead they are folded up, first in parchment paper, and then in felt, and placed in a rectangular box, with narrow strips of india-rubber to prevent contract. Such a cell requires about 16 lbs. of dilute sulphuric acid to charge it. The total weight is about 135 lbs. for each cell. One of these cells, when placed on a circuit of small resistance, in which one of Ayrton and Perry's galvanometers was included, gave the following values of currents:—

For 8 hours	22	webers=	176	weber hours.	
" 4 "	21	" =	84	"	"
" 1 "	20	" =	20	"	"
" 1 "	19	" =	19	"	"
Total 14 hours.			229		

or on an average over 20 webers continuously for 14 hours. The discharge went on after this for seven hours more, when it had stopped to five webers.

DE MERITENS' ACCUMULATOR.

Another modification of the Planté accumulator has been devised by M. De Méritens. In this cell the plates of lead are made up of thin laminæ, folded one upon another like the leaves of a book, or more strictly, like the laths of a venetian blind; the whole being soldered to a stouter framework of lead. The object of this arrangement is to secure a greater amount of effective surface. Two such compound plates are set side by side in a box containing acid; no felt or other separating material being used. The plates require "forming," however, by a longer process than in the Faure cell. This accumulator has been highly spoken of, and showed admirable results at the late Electrical Exhibition in Paris. No examples have yet been brought to England, and I am not aware of any exact measurements having been made of their power or capacity. It is, weight for weight, far more powerful than Faure's cell; and therefore, power for power, is of smaller bulk.

OTHER MODIFICATIONS.

In investigating the properties of secondary batteries, I have tried a number of modifications of the Planté accumulator, with varying success. I have found that almost any oxide or hydrate of lead will answer instead of red lead for the purpose of providing, as in the Faure cell, a material to be converted by a process of formation into the peroxide of lead. Litharge answers well if sufficiently finely divided before being painted on. White lead will even answer, but not so well. Litharge mixed with a small proportion of binoxide of manganese works well. The formation is rapid, but at first the electromotive force is not so high as in the Planté cell. It rises, however, as the process of formation proceeds. The binoxide of manganese is not (see table) so strongly electro-negative a substance as the peroxide of lead. Its presence in the final state would lessen the electromotive force. But happily the manganese gradually dissolves into the acid when its function as an agent to assist the lead in peroxidizing is fulfilled, and by changing the acid a few times it is finally eliminated. The most satisfactory cells I have yet tried were made by painting the lead plates with a coat of the brown peroxide itself, which is obtainable in

commerce, though its cost is about four times that of red lead or of litharge. I find this process by far the most expeditious for making up cells; as indeed might be expected, since it is obviously a stage towards simplification to put on to the lead plates a coating of the very substance which we desire ultimately to produce there. Examination of the plates of a cell in which the process of formation has only just begun, shows that the lead surface must itself be peroxidized and bitten into before the useful action extends to the contiguous portions of oxide or peroxide painted over it, and in some stages a yellow suboxide, probably essentially litharge, appears to be produced as an intermediate product of the reduction of the oxide at the kathode. Of this intermediate yellow product, however, I can find no trace in well-formed cells. As the reduction and peroxidation of the coating only begins where peroxidation of the leaden sheet has begun, the relation of density to maximum polarization, pointed out in an earlier paragraph of my paper, becomes of extreme importance. Plenty of current, and yet of an electromotive force, only just exceeding the maximum electromotive force of the cell, is the rule for charging in the early stages of formation. Could a spongy lead be produced by any simple metallurgical process—like the spongy iron of Bischoff's filters—it would probably prove an admirable substance from which to form electrodes for accumulators.

COMPARISON OF PLANTÉ'S AND FAURE'S ACCUMULATORS.

No very reliable comparisons between the accumulators of Planté and those of Faure, or of De Méritens, have yet been made. Seeing that in each of these, when completely formed, the materials are the same—namely, lead and peroxide of lead immersed in dilute sulphuric acid—the maximum electromotive force must be eventually the same in each. The resistance of a cell is simply a question of size and shape. The relative strength of current actually furnished by these cells should therefore merely vary with their dimensions. The presence, however, of the felt, and its coatings of red lead, introduces resistance into the Faure cell, and as some recent determinations of M. Achard show, a Planté cell will heat a greater length of platinum wire, and do its work three times as quickly as a Faure cell, whose surface is of the same amount. One would also expect *a priori* that the layers of peroxide, formed upon the electrode by the working of the current itself, should be more regular, and yields currents with greater regularity than the artificial and more rapidly-formed layers, made by painting red lead upon the surface. On the other hand, M. Faure points out that, taking cells of equal size, a larger proportion of the weight in his cell consists of the working substance. The weight of red lead placed in his cells being, for equal amounts of surface, about 26 times as much as the weight of peroxide produced by a "formation" during two years on the plates of a Planté cell of equal size. If this be so, it would imply that, though its resistance might be greater, and its rate of working slower than the Planté cell, the Faure cell would accumulate twenty-six times as much energy in an equal space. These figures require yet to be confirmed, and they are hardly borne out by the statistics of M. Regnier. Still less do they justify the extravagant pretensions that have been ignorantly set up on behalf of the enormous powers of the Faure cell—pretensions which have been angrily combated, though it is well to note that neither M. Planté nor M. Faure have taken part in this unpleasant recrimination. The Faure cell will do what the Planté cell will not, take in a greater charge, because it has a greater thickness of the working material, and it gives up its charge less rapidly. The Planté cell will do what the Faure cell of equal weight or surface cannot do, namely produce rapid discharges in currents of greater volume; a property invaluable for the purpose of some of the applications already named.

APPLICATION TO ELECTRIC LIGHTING BY INCANDESCENCE.

Faure's cells have already done good work in providing an efficient means of working incandescent lamps, such as those of Swan and Maxim, for domestic purposes. I have the pleasure of showing you to-night the result of passing through two chandeliers of Edison's lit-

tle incandescent lamps, the current generated by forty of Faure's accumulators. Here are also some of the incandescent lamps of Swan and of Maxim, lit up by the same means. I have to thank the representatives of the various companies for the courtesy that has put at my disposal these means of illustrating my discourse.

Careful and precise measurements have been made by Sir William Thomson and Mr. J. T. Bottomley, using from 20 to 70 Faure cells as a source of current to illuminate some of Swan's lamps.

SWAN LAMP, NO. 1.

No. of experiments.	Cells.	Volts.	Webers.	Volts × webers ÷ 10 = kilogrammeters.	Horse-power.	Candles.	Candles per horse-power.
1	26	56.9	1.21	6.88	.093	11.6	125
2	30	65.5	1.46	9.56	.129	25	194
3	32	70.2	1.64	11.51	.156	42	263
4	33	71.8	1.74	12.48	.170	38	224
5	34	74.1	1.81	13.42	.181	44	243
6	35	76.1	1.82	13.86	.187	55	294
7	36	78.0	1.99	15.52	.210	63	300
8	37	80.3	2.06	16.54	.224	66	295
9	38	81.9	2.06	16.88	.228	76	333
10	39	84.6	2.06	17.43	.235	82	349
11	40	87.0	2.10	18.27	.247	84	340
12	42	90.9	2.17	19.72	.267	102	382
13	44	92.0	2.11	19.96	.270	89	330
14	46	99.1	2.27	21.91	.296	114	385

Carbon of lamp broke with same power, immediately after the measurement of the light was completed.

These measurements have shown that the efficiency is very considerable, and that where from 35 to 50 such cells are available, the light produced by one lamp may range from 300 to 400 candles per horse power, the latter being measured as actually consumed in the lamp. The foregoing statistics of one series of experiments are taken from the paper read by Sir Wm. Thomson at the meeting of the British Association at York, September, 1881. From these experiments, it appears that a high degree of economy in lighting by incandescent lamps is really attained. Should the accumulator be further improved, to reduce the percentage of waste between charging and discharging, accumulators will play a very important part in future installations, provided they can be constructed at a prime cost, lower than the present figures.

At the Paris Exhibition of Electricity, Faure's batteries have been doing excellent work. The following details of the separate installations will give an idea how many cells are required for a given number of Swan's lamps:

	Swan lights.	Faure cells.
Vestibule	23	56
Kitchen	4	
Bath room	2	
Telephone room (No. 7)	17	29
Telephone room (No. 8)	18	29
Exhibit of the Campagnie La Force et La Lumieres.	34	56

FURTHER APPLICATIONS OF ACCUMULATORS.

In an article on electric storage, which appeared in *Nature*, on June 2, 1881, I pointed out the usefulness of accumulators in the following words:

"The uses for such secondary batteries may be of three kinds: 1. They may serve as portable supplies of electricity to be left and called for to recharge when exhausted. 2. They may serve to accumulate supplies of electricity from dynamo-electric machines, and store them until required for furnishing electric light or motive power on a small scale. 3. They may serve as equalizers of electric currents in a system in which the supply is liable to fluctuations. Suppose, for example, a dynamo-electric machine is employed to produce electric light. Any least thing which alters the speed of the machine, even for an instant, makes the light flicker and change in intensity; while the breakage of the engine strap would at once cause total darkness. But if a secondary battery of suitable dimensions and power were inserted across the circuit, between the dynamo-machine and the lamp, the inequalities of the current would be greatly modified. When the light was not in use, the battery would store up the current. If the engine failed, the battery would at once put forth its power. It is probably in this direction that the secondary battery will find no unimportant field of usefulness."

Of the first and second of these purposes you have an illustration to-night, this medical Planté cell and these forty Faure cells having been brought to this room charged, for the purpose of showing you their powers. The third possible use has been also emphasized by Sir William Thomson, who, at the September meeting of the British Association, gave details of a scheme of automatic adjustments to make and break the circuit between the dynamo-machine and the secondary battery, so as to guard the former from damage and the latter from waste.

As to portability, for such purposes as domestic lighting the cost and risk of carting the heavy cells to and fro is probably prohibitory. For special purposes, such as those of galvano-cautery already mentioned, the Planté accumulator is certainly superior to the Faure, since it is lighter, and at the same time gives up its charge more rapidly, though its storage power for cells of equal bulk is less than that of the Faure.

MAXIMUM TEMPERATURE ATTAINABLE BY A CELL.

In connection with the subject of obtaining a high temperature by means of a cell, it may not be out of place to point out that the very high electromotive force of these accumulators (about 2.2 volts), exceeding that of any single cell of any other kind, carries with it the possibility of obtaining with such a cell a lower electromotive force. This discovery is due to Lorenz, of Copenhagen, who, in a very remarkable paper published (in *Wiedemann's Annalen*) in August last, upon the relation between the conducting power of metals for heat and for electricity, has shown that the highest possible temperature which a cell can raise any part of its circuit is proportional to its electromotive force. The highest point to which a Daniell's cell, however large, can raise a conductor is, according to Lorenz, 3,327° above the zero of the Centigrade scale. The limiting temperature for a Planté or a Faure cell is 6,927°.

APPLICATION TO BLASTING AND TORPEDO FIRING.

The great calorific power of these accumulators, due as much to their small internal resistance as to their high electromotive force, is doubtless of great importance in the application to the firing of torpedoes and blasts in mining. The special batteries now used might economically be replaced by one or two storage cells provided with a charging battery of half a dozen of Daniell's cells, whose slowly-produced currents could be thus accumulated.

APPLICATION TO PERFECTION OF THE TELEPHONE.

Another application of the secondary batteries which has occurred to me, and which, on a small scale, I have tried with success, is in connection with telephone transmitters. There is still room for improvement in the telephone; at its best the speech it transmits is neither so loud, nor so distinct, nor so free from extraneous sounds, as might be desired. The fault lies almost wholly with the transmitters. They will not transmit loud sounds distinctly. The strength of the currents generated by the Bell telephone, used as a transmitter, is limited by conditions which are wholly distinct from those which limit the possible strength of the currents transmitted by a "microphone," or "carbon transmitter;" my remarks must be understood as applying to the latter kind of instrument. If you put a very strong current on to a microphone, so as to make it, as you think, speak more loudly, the end is not attained. The points of contact get hot; there is a whirring and wheezing heard at the receiving end; and the speech degenerates into confusion. There is then, a practical limit to which the strength of current flowing through a microphonic current can be carried. Some of the transmitters in use employ three or four points of contact, the current being carried through these either in series or in branching arcs. In the first of these two cases, the limitation is only pushed back by one stage. In the latter case, one only of the contacts usually does the real work of transmitting, namely, that whose resistance is least. I propose to increase the power of a transmitter by employing a multiple microphone, so arranged that a fairly strong current shall pass through each point of contact, and that the current through each contact shall be independent of that

through the rest. I therefore arrange all the individual microphones in parallel arc, in the line circuit, but provide each with its own battery. A hundred microphones thus united, and simultaneously acted upon by the voice, will each add their own quantum to the total effect in the circuit; and the result will be loud and distinct speech. But a hundred microphones so arranged, each with its own battery, implies two or three hundred cells. Here the secondary cell comes in with great advantage. I propose to use very small storage cells, each consisting of two small leaden plates, or wires, dipping into dilute sulphurid acid, and properly "formed." Two such cells may be connected with each microphone, and the whole, being already arranged in parallel arc in the circuit, can be kept charged by merely placing across the circuit six Daniell's cells, to be switched off when the transmitter is to be used, and switched on again when the transmitter is no longer required. As yet only a small and rough model of this "secondary circuit transmitter" has been made; but it is extremely satisfactory in its action, and promises to be the first of a useful and important application.

APPLICATION TO RAILWAY PURPOSES.

A proposition is now about to receive practical application to light a railway train with Swan's lamps, by means of Faure's accumulators. This is the new Pullman-car train, plying four times per diem between London and Brighton, which will be lit by forty Faure cells. The trial trip is to be arranged in a few days. A train might be contrived to store electricity gradually, by a dynamo-electric machine fixed to the axles of the carriages, and thus to have a supply of electricity, to be turned on when the train passes through a dark tunnel.

APPLICATION TO UTILIZATION OF WIND AND WATER POWER.

And, lastly, though by far the most important of all the innumerable possibilities opened out by the storage battery, is its application to the problem of utilizing and transmitting the energy derived from wind or water power. The difficulty of utilizing water power is that, that it is so often not to be found where it is desired; the difficulty with power is that it fails too often just when it is wanted. The reversibility of the dynamo-electric machine solves the difficulty of the where by giving us a means of electric transmission. The reversibility of the voltaic cell will probably solve the difficulty of the when, by giving us the means of storing energy, when we can get it, until such time as required for use. The accumulator will probably play an important part also in the distribution as well as in the storage of power transmitted from a distance, and thus become the ally of the dynamo-electric machine. It is certain that we cannot, with our diminishing coal fields, long afford to neglect these other sources of natural power. In his Presidential Address to the Mathematical and Physical Section of the British Association, Sir W. Thomson has dealt with this question, and has come to the conclusion that, though tidal power be practically unlimited, it will not pay economically to build tide basins to utilize this power, as the reclaimed land would be of greater productive value, and that, therefore, we must not look to the tides. If I may venture modestly to differ from so great an authority, I would point out that there are cases where no great expense would be incurred in utilizing natural tidal areas as basins, where the area so utilized could not possibly be reclaimed or worked as profitable land, and where the rise and fall of the tide is greatly above the figure which he assumed. The River Avon at Bristol furnishes a case in point. It requires but a few yards of embankment to be turned into an available tidal area. The average rise and fall of tide at the city of Bristol, five miles from its mouth, is 23 ft. According to calculations I have made from the average volume of water displaced up and down each tide, there are no fewer than 20 billions of foot-pounds of energy wasted every year, or enough to charge ten million Faure cells. At the mouth of the river the total annual tidal energy thus running to utter waste cannot be less than 50 billion foot-pounds; and in the rapid currents of the River Severn, with their enormous tides of great volume, the tidal energy must be practically unlimited. A tenth part of the tidal energy in the gorge of the Avon would light the city of Bristol. A tenth part

of the tidal energy in the channel of the Severn would light every city, and another tenth would turn every loom and spindle and axle in Great Britain. But the power would have to be not only transformed and transmitted, but stored, to be available for such ends. Accumulators are therefore a necessary feature in any scheme to utilize the intermittent forces of the tides. Whether the present form will prove adequate to the purpose, the future must decide. Probably the present accumulator bears as much resemblance to the future accumulator as a glass bell jar, used in chemical experiments for holding gas, does to the gasometer of a city gas works, or as James Watt's first model steam engine does to the engines of an Atlantic steamer. When the practical accumulator of the future has been built, it will be more easy to say what will be the limit of its applications. There are, as I have sufficiently shown, immense possibilities in store. Electrical railways and electrical tramways are now existing facts. Many months will not elapse—or it will be an eternal disgrace to the first city in the world—before the fœtid and poisonous atmosphere of the Metropolitan Railway is replaced by a pleasant and salubrious air, rich in fragrant ozone; and the like revolution will not be long delayed in many quarters where reform is far less imperative. In all these changes the accumulator will have its part to play. A reserve of electrical energy stored till wanted will be a necessary part of all systems for electric distribution, whether for the purpose of lighting, or for motive power.

In conclusion, I would point out how the invention of the accumulator for storing the energy of electric currents has arisen out of the study of an obscure and unpromising detail in the science of electricity—the phenomenon of so-called "polarization." Regarded by most experimenters merely as a trivial but disturbing fact in the construction of voltaic batteries, to be put down or got rid of by whatever means, it has been developed, and, mainly by the long and patient researches of one man, M. Gaston Planté, and finally by the brilliant idea struck out by M. Faure, been turned into one of the most fertile and promising features in the development of the science. It is the old story over again of the reward which follows patient investigation of unexplored corners and waste places of science. Grand principles and sweeping generalizations are magnificent weapons to the scientific investigator. The principle of the conservation of energy has reaped triumph after triumph; and a kindred generalization in the science of electricity is destined, as I think, to lead to scarcely less important results. But there are other ways of adding to the sum of human knowledge, beside the following out of grand sweeping principles. There are half-forgotten observations, unconnected, unexplained, and often exceptional in character, every one of which has a significance of its own—residual phenomena, every one of which is, to the scientific man, of a value beyond price. He who investigates them patiently may find the clue to their meaning, and reap a rich reward from them. They are the finger posts in the high road of scientific discovery.

DISCUSSION.

The Chairman, in proposing a vote of thanks to Professor Thompson, said that gentleman had gone a long way back for the origin of secondary batteries, viz., nearly to the time of the invention of the voltaic battery itself; there was, however, a very interesting little book, which had been shown at the Paris Electrical Exhibition, a note-book of Galvani's, in which it was recorded that in 1795, *i.e.*, five years before the discovery of the voltaic pile, he had made an experiment, and discovered a secondary battery, and also made use of a galvanometer, which was not quite the same as that which Professor Thompson stated was used by Ritter. The primary battery which he employed was the electric eel, by means of which he gave a charge to the limbs of a frog, and then using the frog as a secondary battery, and himself as a galvanometer, he was able to get a secondary electric discharge. With regard to the vexed question of electromotive force, he was glad to see that there were figures put forward, though there had not been time to go into them, which confirmed the results arrived at by himself with regard to the amount of electromotive force of the Planté cell. The results arrived at

by Sir William Thomson show that the electromotive force of the Planté cell lies between 2 and 2½ volts. The development of this subject had been very rapid indeed. Only a little more than four months ago the Faure battery was quite unknown in England; it was in fact shown for the first time in July, when he had the opportunity of showing it at King's College, through the kindness of Mr. Faure, and demonstrating how the electric light might be obtained by its means; but since then its development had been very rapid. With regard to the amount of work capable of being stored up, they had heard of millions and billions of units, which he feared would not convey a very definite idea to the general public; but perhaps the Electrical Congress of Paris had done a little in suggesting names for electrical units, and if instead of hearing of such enormous numbers of foot-pounds in connection with electricity, they could get the work represented by so many "volt-coulombs," putting together the units of electromotive force and quantity, it would be simpler, and a better idea would be conveyed of what the unit really was.

Prof. Abel, F.R.S., said he had been greatly interested and instructed by this very lucid paper; a more complete account of the very rapid development of this subject could not have been given in so short a space of time. He did not pretend to be a scientific electrician, though he dealt sometimes with the practical applications of electricity, and he had listened therefore with the greatest interest to what Professor Thompson had told them of the recent developments which the secondary batter had received, and was still receiving. As he listened to him, he began to feel sanguine that these applications might be realized. There were some directions in which, if they could obtain a moderately portable battery, which could be re-charged in a reasonable time, he could see applications that would be of the highest importance. He alluded to the illumination of coal mines, a matter in which he was particularly interested; and he did begin to hope that they might before very long realize the sanguine expectations of some philosophers, and that electricity would be used for this purpose. Up to quite recently, he had been very doubtful, for, having seen some of the first attempts, he had had reason to fear that the necessity for conducting wires along the workings, and in places liable to great falls of the roof and various kinds of accident, might lead to injuries, not merely fatal to the illumination, but also, possibly, to the lives of the miners, in consequence of the production of sparks which might ignite the inflammable gases. If, however, they could see their way to transport to the furthermost parts of the mine a convenient form of secondary battery, with which they could work readily with only short lengths of wire, and if small portable lamps could be attached to the men's caps, there would be accomplished what might be considered the most perfect and safe illumination of a mine possible. This he hoped would be done before many years; there were, no doubt, many other directions in which the stored-up energy might be very advantageously used.

Prof. Frankland, F.R.S., said this invention of the storage of electricity was most important in connection with the applications of this force which were being made at the present time. It was a reproach not altogether unfounded, against the dynamo-current as ordinarily produced, that it might, at any moment, fail from the accidents of machinery or other causes; but such failures would be entirely obviated by the aid of a suitable and effective storage battery, of the kind invented by Planté or Faure. He should like to ask Professor Thompson whether, in his numerous experiments on this subject, he had gone at all into the subject of the length of time this force could be kept stored up in the battery. This was an important point, which, he feared, had been a good deal neglected hitherto. He should like to know whether there was any considerable amount of leakage, and, if so, how much, and for what length of time a battery might be expected to retain its charge. He could only conclude by expressing his best thanks for the very able lecture Professor Thompson had given.

Mr. Evans asked if a number of Faure accumulators could be used to store up the power derived from water wheels, so

that the wheels of turbines might work during the night, and the power thus stored be used during the day.

Mr. Shoolbred wished to add a word or two in regard to the De Méritens' battery. He had lately returned from a visit to Paris, and he found the form in which De Méritens was now making his battery, in a practical way differed considerably from the form in which they first appeared, and which had been shown on the screen. Each cell consisted of a solid lead, filled in with thin sheets of lead, less than a millimeter in thickness. It was much simpler than either the Faure or the original Planté battery; whether it was as efficient, yet remained to be seen; but the one in the exhibition worked very well. M. De Méritens had informed him that it took from fifteen to twenty days to form the cell, not, as he had understood Dr. Thompson to say, six months. He had hoped to have got one to bring over, but could not do so. With regard to the figures in the table (see p. 211), and which he saw were Sir William Thomson's, he wished to say that, by the kindness of Sir William Thomson he was enabled to repeat the experiments for photometric measurements, with the aid of Mr. Keats, of the Metropolitan Board of Works, who kindly brought over his own photometer, and the candle power came out even higher than as given by Sir William Thomson.

The Secretary said he was happy to announce that he had seen M. De Méritens very recently in Paris, and he prom ised that he would send over a complete set of his batteries to the Society of Arts, as soon as they were ready in January or February next.

Two further questions having been asked, viz., as to the expense of producing the light, and why the electric energy in the secondary battery was not given off all at once.

The Chairman put the vote of thanks to the meeting, when it was carried unanimously.

Professor Thompson having acknowledged the compliment, said he would answer the last question first, and he might do so by asking another. How was it that a voltaic battery gave off its energy gradually, instead of going off with a bang? You could not get zinc to dissolve at more than a certain rate; nor in the case of the stored battery could you get the peroxide to reduce itself, and the reduced lead to oxidize itself, at more than a certain rate. Besides, if by any possibility, the battery did go on at too great a rate, it would polarize itself—it would begin to reduce the side towards which the current was going, and so bring down the amount of current passing. The rate at which the action went on depended on the conducting power of the lead, its resistance to electricity, and the amount of surface exposed; also on the condition of the deposited substances. A piece of coal did not give up its energy all at once when put into the fire. As a matter of fact, the action at the surface did not go on at more than a certain rate. As to the expense he should not like to give figures which he could not stand by in a court of justice, and therefore he would not give any. At the same time he should like to explain that he believed the expense of the light then shown would be less, considerably, than it would cost to produce the same amount of light by making gas. For a steam engine with the necessary plant to work a small dynamo machine, and the necessary accumulators to store it up sufficiently to give out for four or five hours a light they saw before them, would certainly not cost as much as to have to set up a gas-generating apparatus with a small gasometer, and the pipes to produce gas of equivalent value. When the prime cost was less to begin with, he had simply to consider the cost of maintenance; and he was quite certain that the gas put into a gas engine to work a dynamo machine would produce more light electrically than it would if burned directly. There was now no question on that score. With regard to the water wheels, if they were used to work a dynamo machine for fourteen hours, and during those fourteen hours the electricity was stored up in an accumulator, or a set of accumulators, it would be a much cheaper and better way of obtaining and storing electricity for lighting, or any other useful purpose, than setting up a large dynamo machine to produce the light directly. For instance, in the Savoy Theater they had a large number of lights produced directly

from dynamo machines driven by steam engines, and the lights, when they were all on, flickered up and down, on account of inequalities in the driving. If they employed one-fifth or one-sixth of the driving power and worked the engines all day into accumulators in the cellars, he believed they could work the lights not only far more steadily, but far more economically. He had been asked by Professor Frankland what waste there was by lapse of time in these accumulators, and he had made some inquiries that morning as to what happened on a practical scale, and he was told by Major Seaver that he reckoned there was about 10 per cent. per week loss from batteries left idle. As a fact, they really did not yet know the conditions under which the leakage took place, whether by surface conductivity, by electrical convection, or what. There was a certain amount of waste, but, nevertheless, there were cases in which a very considerable amount of the charge had remained for a considerable time. For instance, there was the celebrated box which was sent from Paris to Sir William Thomson, containing four small cells rolled up in spirals, and packed together. When they went to Glasgow they contained the million foot-pounds; they had been partly discharged again and again, and yet they would still work a small lamp, and would give light for many hours probably. Then some of the Planté cells would retain their charge for a long time. The medical cell he had shown them was brought from Dublin by Professor Barrett a short time ago. He had used it in Dublin. It was then sent to him at Bristol, where it was used, and then it came there, and there was a considerable amount of force in it yet, though, unfortunately, in an evil moment they broke the glass, and half the liquid ran out. The Planté cell held its charge a long time, and he did not see why the Faure should not be equally successful. With regard to the De Méritens battery he did not mean to be taken literally when he said it took some six months to get the cells into a working state, but he did think it was a step backwards to use Planté's method of long-continued electrical action, instead of Faure's more rapid process of producing the peroxide from red lead. He must conclude by expressing his thanks to those who had so kindly assisted him, by lending apparatus for the purpose of the lecture.

During part of the evening the room was lighted by a number of Edison lamps, worked by Faure batteries, lent by the Société de Force et de Lumiere. Incandescent lamps by Swan and Maxim were also shown at work.

Weisnegg's Laboratory Stove.—This apparatus, which is installed in the chemical laboratory of the Municipality at Paris, is designed to maintain a constant temperature within it. This is effected by regulating the supply of gas which heats the stove, and the regulation is effected in the following manner. A mercury thermometer tube passes into the stove from the outside, and the rising of the mercury above the height corresponding to the temperatue at which it is desired to keep the stove is caused to partially close the orifice of the gas supply pipe. The result is that the temperature in the stove falls, and hence the mercury sinks to its old level. The stove is lined inside with plaques of earthenware, and a glass door is provided in front so as to allow the evaporations to be watched. While upon this subject of stoves we may mention that Herr Miske, of Dresden, has invented an acetate of soda stove, which is an application of the property possessed by this chemical, of parting with its heat slowly, after having been fused. It will be remembered that certain Swedish railway companies some time ago first adopted the plan of filling their footwarmers with acetate of soda, and fusing it before placing them in the carriages, the result being that the warmers retained their heat very much longer than those filled with hot water. Herr Miske found that by using a mixture of ten volumes of hyposulphate of soda to one volume of acetate, the time of cooling could be still further extended, and constructed a stove in which the heat is supplied by three flat cases of the fused salts placed between two cylinders, the outer of which is perforated with numerous small holes to allow the heated air to escape into the room. The stove runs on castors and can thus be removed from one room to another.

THEORY FOR TURBINE WATER WHEELS.

By GUSTAF ATTERBERG.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

The equations which must be satisfied in calculating the dimensions of turbine wheels will now be given. They are (4.), (16), (23), (24) and (26), which by transformations give the equations required.

A. *For turbines where the water discharges into the air:*

1. When the angles a and β or the value n are known:

$$\cot a+\cot\beta=\frac{\pi}{30}\cdot\frac{r_1 n}{c.\sqrt{\mu}\sin a} \quad . \quad . \quad (27).$$

$$\cot\gamma=m.\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\sqrt{m^2(\cot a+\cot\beta)^2-}$$

$$\overline{-2\cot a(\cot a+\cot\beta)+\frac{1}{\mu\sin^2 a}-}$$

$$\overline{-\frac{1}{m^2}\left(\frac{\xi_1}{\xi_2}\right)^2\cdot\left(\frac{B_1}{B_2}\right)^2} \quad . \quad . \quad . \quad (28).$$

$$\cot\varphi=\cot\gamma-m^2\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}(\cot a+\cot\beta). \quad (29).$$

$$\frac{V_1}{c}=\sqrt{\mu}\sin a(\cot a+\cot\beta) \quad . \quad . \quad (30).$$

and equation (24) are used.

2. When the angles a and γ are known, then:

$$\cot\varphi=\cot\gamma-\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\cot a-$$

$$\sqrt{1+\cot^2\gamma-\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2\left(\frac{m^2}{\mu\sin^2 a}-\cot^2 a\right)} \quad . \quad . \quad . \quad . \quad (31).$$

$$\cot\beta=\frac{1}{m^2}\cdot\frac{\xi_1}{\xi_2}\cdot\frac{B_1}{B_2}(\cot\gamma-\cot\varphi)-\cot a \quad (32).$$

and the equations (30) and (24) are used.

3. When the angles a and φ are known, the equations (23), (30), (32) and (24) are used.

4. If the angle $a=90°$ and the angle β or the value n is known, then:

$$\cot\beta=\frac{\pi}{30}\cdot\frac{r_1 n}{c.\sqrt{\mu}\sin a} \quad . \quad . \quad . \quad (33).$$

$$\cot\gamma=m.\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\cdot$$

$$\sqrt{m^2\cot^2\beta+\frac{1}{\mu\sin^2 a}-\frac{1}{m^2}\left(\frac{\xi_1}{\xi_2}\right)^2\cdot\left(\frac{B_1}{B_2}\right)^2} \quad . \quad (34).$$

$$\cot\varphi=\cot\gamma-m^2\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}.\cot\beta$$

and equation (24) are used.

5. If the angle $a=90°$ and the angle γ is known, then:

$$\cot\varphi=\cot\gamma-$$

$$\sqrt{1+\cot^2\gamma-\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2\cdot\frac{m^2}{\mu\sin^2 a}} \quad . \quad (35).$$

$$\cot\beta=\frac{1}{m^2}\cdot\frac{\xi_1}{\xi_2}\frac{B_1}{B_2}(\cot\gamma-\cot\varphi) \quad . \quad . \quad (36).$$

and equations (30) and (24) are used.

The value of B_2 that gives the best efficiency of the wheel is:

$$\frac{B_2}{B_1}=\frac{\xi_1}{\xi_2}\cdot\frac{\sqrt{\mu}.\sin a}{m}\sqrt{\frac{2(1+\cot^2\gamma)}{1+\sqrt{1+\cot^2\gamma}}} \quad . \quad (37).$$

and then are η from equation (24)′ and φ constant values.

If $\cot\gamma=4$, then:

$$\frac{B_2}{B_1}=2{,}58\,\frac{\xi_1}{\xi_2}\cdot\frac{\sqrt{\mu}\sin a}{m} \quad . \quad . \quad . \quad . \quad (37).'$$

6. If the angle $a=90°$ and the angle φ is known, then:

$$\cot\gamma=\frac{\cot^2\varphi-1+\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2\cdot\frac{m^2}{\mu\sin^2 a}}{2\cot\varphi} \quad (38).$$

and the equations (30), (32) and (24) are used.

7. If the angle a is known and the angle $\varphi=90°$, then:

$$\cot\gamma=\frac{\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2\cdot\frac{m^2}{\mu\sin^2 a}-1}{2\frac{\xi_2}{\xi_1}\frac{B_2}{B_1}\cot a} \quad . \quad . \quad . \quad (39).$$

$$\cot\beta=\frac{1}{m^2}\cdot\frac{\xi_1}{\xi_2}\cdot\frac{B_1}{B_2}\cot\gamma-\cot a \quad . \quad . \quad (40).$$

and the equations (30) and (24) are used.

B. *For turbines where the water discharges under the lowest surface of the water in the tail race.*

1. When the angles a and β or the value n are known, then:

$$\cot a+\cot\beta=\frac{\pi}{30}\cdot\frac{r_1 n}{c\sqrt{\mu}\sin a} \quad . \quad (27).$$

$$\cot\varphi=\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\cdot\left(\frac{1}{2\mu\sin^2 a(\cot a+\cot\beta)}-\cot a\right) \quad . \quad (41).$$

$$\cot\gamma=\cot\varphi+m^2\cdot\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}(\cot a+\cot\beta) \quad (42.)$$

and the equations (30) and (24) are used.

2. When the angles a and γ are known, then:

$$\cot\varphi=\tfrac{1}{2}\left(\cot\gamma-\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\cdot\cot a\right)-\sqrt{\frac{1}{4}\left(\cot\gamma+\frac{\xi_2}{\xi_1}\frac{B_2}{B_1}\cot a\right)^2-\frac{m^2}{2\mu\sin^2 a}\left(\frac{\xi_2}{\xi_1}\right)^2\left(\frac{B_2}{B_1}\right)^2} \quad . \quad (43).$$

and the equations (32), (30) and (24) are used.

3. When the angles a and φ are known, then equations (26), (30), (32) and (24) are used.

4. If the angle $a=90°$ and the angle β or the value n is known, then:

$$\cot\beta=\frac{\pi}{30}\cdot\frac{r_1 n}{c\sqrt{\mu}\sin a} \quad . \quad . \quad . \quad . \quad (33)$$

$$\cot\varphi=\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1}\cdot\frac{1}{2\mu\sin^2 a\cot\beta} \quad . \quad . \quad . \quad . \quad (44).$$

and equations (29), (24) and (30) are used.

5. If the angle $a=90°$ and the angle γ is known, then:

$$\cot\varphi=\frac{\cot\gamma}{2}-\sqrt{\frac{\cot^2\gamma}{4}-\frac{m^2}{2\mu\sin^2 a}\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2} \quad . \quad (45)$$

and equations (36), (30) and (24) are used.

The value of B_2, that gives the best efficiency of the wheel, is:

$$\frac{B_2}{B_1}=\frac{\xi_1}{\xi_2}\cdot\frac{\sqrt{\mu}\sin a}{m}\cdot\sqrt{2}\cdot\cot\gamma\frac{\sqrt[4]{1+\cot^2\gamma}}{1+\sqrt{1+\cot^2\gamma}} \quad . \quad . \quad . \quad . \quad (46.)$$

and then are η from equation (24)′ and φ constant values.

If $\cot\gamma=4$, then:

$$\frac{B_2}{B_1}=2{,}24\frac{\xi_1}{\xi_2}\cdot\frac{\sqrt{\mu}\sin a}{m} \quad . \quad . \quad . \quad . \quad (46.)'$$

6. If the angle $a=90°$ and the angle φ is known, then:

$$\cot\gamma=\frac{1}{\cot\varphi}\cdot\left\{\cot^2\varphi+\frac{m^2}{2\mu\sin^2 a}\cdot\left(\frac{\xi_2}{\xi_1}\right)^2\cdot\left(\frac{B_2}{B_1}\right)^2\right\} \quad . \quad . \quad . \quad . \quad . \quad (47).$$

and equations (30), (32) and (24) are used.

7. If the angle a is known and the angle $\varphi=90°$, then:

$$\cot\gamma=\frac{1}{2\cot a}\cdot\frac{m^2}{\mu\sin^2 a}\cdot\frac{\xi_2}{\xi_1}\cdot\frac{B_2}{B_1} \quad . \quad . \quad (48).$$

and equations (30), (40) and (24) are used.

Is $\mu=1$, then is:

$$\beta=180°-2a.$$

If when the turbine is calculated, and the values of ξ_1 and ξ_2 are found to be not satisfactory, then without any more change of the details of the wheel, better values of ξ_1 and ξ_2 may be assumed, if at the same time the values of B_1 and B_2 are changed, so that they become $B_1'=\frac{\xi_1}{\xi_1'}\cdot B_1$ and $B_2'=\frac{\xi_2}{\xi_2'}\cdot B_2$, because the product of B and ξ is in all equations and they are never separated from each other.

Turbines constructed without consideration of the best efficiency may often be used in practice, for instance, when a given velocity of the wheel is wanted. Therefore the equations that must be used in calculating these wheels have been mentioned. For wheels where $a=90°$ the angle φ cannot be 90°, as the wheel then would have an immense velocity and the angles β and γ would be equal to zero. The best way to calculate these wheels is to assume the value of $\cot\gamma$ to be as great as it can be made in practice, as the greater this value the better is the efficiency obtained. A good value of $\cot\gamma$ is $\cot\gamma=4$. For these

wheels equations (37) and (46) should be used, as by their use the best efficiency is obtained.

The form of the vanes in the wheel.—The vane ought to be constructed with much care as upon its form depends the flow of the water in the wheel. Its form is arbitrary between narrow limits, but it cannot be assumed at will if a given flow is desired. The number of the vanes ought to be the least possible, because the water then gets a more uniform flow. Fig. 8 shows a wheel with only four vanes.

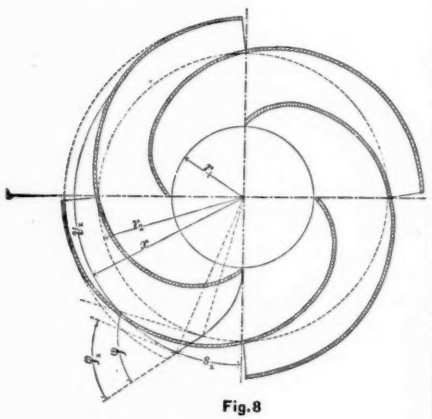

Fig. 8

From this figure it will be seen that the vanes ought to be lengthened, so as to enclose the water till it discharges at that circumference of the wheel which corresponds to the radius r_2. For wheels where r_1 is larger than r_2 many vanes must be used, because for those wheels it is advantageous to make the difference $r_1 - r_2$ as small as possible.

In order to obtain a good form for the vane it is best to construct it from the form of the curve which one particle of water describes when it passes through the wheel.

The volume Q of water flows through the wheel per second. The time required for a particle of water to pass through the wheel between the circumferences which have the radii r_1 and x is:

$$t_x = \frac{\text{The volume of water enclosed between the radii } r_1 \text{ and } x}{Q}$$

If—see Fig. 4—the surface $a_1 a_1 d_1 d_1 = A_x$, then:

$$t_x = \frac{2\pi a_x \xi''.A_x}{2\pi r_1 B_1 \xi_1 \sqrt{\mu}\sin a.c}$$

when a_x is the distance from the center of gravity of the surface A_x to the center of the wheel. After reducing:

$$t_x = A_x \cdot \frac{a_x}{r_1} \cdot \frac{\xi''}{\xi_1} \cdot \frac{1}{B_1} \cdot \frac{1}{\sqrt{\mu}\sin a} \cdot \frac{1}{c} \quad (49).$$

The distance a point of the wheel at the distance x from the center of the wheel moves in the time t_x is:

$$y_x = V_x \cdot t_x$$

when V_x is the velocity of the wheel at this point. This velocity is:

$$V_x = \frac{x}{r_1} V_1$$

By use of this value and equation (4) it is found that:

$$y_x = \frac{A_x}{B_1} \cdot \frac{x}{r_1} \cdot \frac{a_x}{r_1} \cdot \frac{\xi''}{\xi_1} (\cot a + \cot \beta) \quad (50)$$

If the line that represents the path which a particle of water describes, is known, then is the form of the vanes obtained by assuming several values for x, and from them finding the corresponding values of y_x, which are set from this line along the circumferences of the wheel, which correspond to the values of x. These distances y_x determine the form of the vanes.

In order to obtain the best form of the path in which a particle of water ought to move, when it passes through the wheel, we will consider that the water moves with a constant acceleration in direction opposite from that in which the wheel is going. Then the following equations for a uniform accelerated motion can be used, namely:

$$v = v_0 + at$$

$$S = v_0 t + \frac{at^2}{2}$$

if v_0 is the velocity at the beginning of the time t, v the velocity at the end of the same time t, a is a constant acceleration and S the distance passed through in the time t. If the course of the water, in direction opposite from that in which the wheel is going, is considered relative to the direction ae'—see Fig. 3—in which the water enters the wheel,

then is $v_0 = o$ in the general equations, and,

$$v = at \quad . \quad . \quad . \quad . \quad . \quad (51).$$

$$S = \frac{at^2}{2} \quad . \quad . \quad . \quad . \quad . \quad (52).$$

For the radius r_2—see Fig. 3—the value for v is

$$E = \frac{\sin(\delta + \varphi)}{\sin\delta} \cdot c_2$$

if the line ae' represents the direction in which the water enters the wheel, δ the angle between this line and the tangent to the circle in the point e', and the line $a\ b\ c\ d\ e\ f$ the path of a particle of water. The value of a in equations (51) and (52) is then:

$$a = \frac{v}{t} = \frac{\sin(\delta + \varphi)}{\sin\delta} \cdot \frac{c_2}{t}$$

The distance which the water has been removed for the radius x is according to equation (52)

$$S_x = \frac{\sin(\delta + \varphi)}{2.\sin\delta} \cdot c_2 \cdot \frac{t_x^2}{t}$$

From equation (49) the value of t is found to be:

$$t = A \cdot \frac{a}{r_1} \cdot \frac{\xi}{\xi_1} \cdot \frac{1}{B_1} \frac{1}{\sqrt{\mu}\sin\alpha} \cdot \frac{1}{c}$$

By use of the values of t and t_x we have:

$$S_x = \frac{\sin(\delta + \varphi)}{2\sin\delta} \frac{A_x^2}{A} \cdot \frac{(\xi'')^2}{\xi.\xi_1} \cdot \cdot \frac{a_x^2}{a.r_1} \cdot \frac{1}{B_1} \frac{1}{\sqrt{\mu}\sin\alpha} \cdot \frac{c_2}{c} \quad . \quad . \quad . \quad . \quad (53).$$

From Fig. 3 it is easy to find that:

$$\cos\delta = \frac{r_1}{r_2}\cos\alpha$$

Also after some transformations, by use of this equation is:

$$\frac{\sin(\delta + \varphi)}{\sin\delta} = \sin\varphi. \cdot \left(\cot\varphi + \frac{\cot\alpha}{\sqrt{m^2 + \cot^2\alpha(m^2 - 1)}}\right) \quad . \quad . \quad . \quad (54).$$

From equations (15), (53) and (54) is then found that:

$$S_x = \frac{A_x^2}{2.A} \cdot \frac{(\xi'')^2}{\xi.\xi_2} \cdot \frac{a_x^2}{a.r_2} \cdot \frac{1}{B_2} \cdot \cdot \left(\cot\varphi + \frac{\cot\alpha}{\sqrt{m^2 + \cot^2\alpha(m^2 - 1)}}\right) \quad . \quad . \quad . \quad (55).$$

If $x = r_2$ then is:

$$S_0 = \frac{A}{2} \cdot \frac{\xi}{\xi_2} \cdot \frac{a}{r_2} \cdot \frac{1}{B_2} \cdot \cdot \left(\cot\varphi + \frac{\cot\alpha}{\sqrt{m^2 + \cot^2\alpha(m^2 - 1)}}\right) \quad . \quad . \quad . \quad (55).'$$

By use of equation (55) the line that represents the path of a particle of water in its passage through the wheel may easily be constructed, and from this is then obtained, by use of equation (50), the form of the vanes. By use of such a form is obtained an almost uniform pressure of the water against the vanes, in the direction of the motion of the wheel.

If it should be desirable to construct the vanes in an easier way, then equation (55) may be avoided, and only equation (50) used. Then ought the path of the water between the radii r_1 and r_2 to be constructed as a parabola, and in such a way as will now be shown. In order to construct this line, the point e—see Fig. 3—is assumed, and through it a line fg is drawn, so that the angle between this line and the tangent to the periphery at the point e of the wheel is φ, and a parabola is drawn as Fig. 6 indicates, so that the lines ae' and fg are tangents at the points a and e. Assume that this parabola represents the path of a particle of water. It ought to be observed, that when the water has left the circumference, which corresponds to the radius r_2, the path ef ought to be a straight line, because at this part of the wheel the water has to perform no work. When now the path $abcdef$ of a particle of water is known, the equation (50) is used to obtain the form of the vanes. In order to find the form of the vanes, the form of the cross section of the wheel must be known, so that the value A_x can be obtained; but the form of the cross-section of the wheel depends upon the path of the water through the wheel if a good flow of the water is desired. For that reason the line which represents the path of a particle of water must at first be approximately assumed, in order by its use to construct the cross section of the wheel. This cross section is easily obtained if it is assumed that the water will have to spread gradually.

When the cross section of the wheel is found, and from it the curve, that represents the path of a particle of water, is

obtained from equation (55), and it is found of different shape from the line approximately designed, then no change of the cross section of the wheel should be made because the approximate form and the calculated one can not be very different. When wheels are to be designed the use of equation (55) can be avoided as before stated. In order to obtain the cross section of the wheel assume the line *abcdef*—see Fig, 3—to be be known. Divide this line in any number of parts and set their rectified lengths in the same order on the line $a'f'$—see Fig. 5. The line aa represents the width of the wheel at the inlet, and ee the width at the outlet. Divide the line at, which is drawn through the point a, parallel to the line $a'f'$, in the point m, so that the line am is equal to the line mt, and draw a straight line through the points e and m. Draw in such way as Fig. 6 indicates, a parabola through the points a and e, so that the lines am and mf become tangents to this curve. The surface $aaff$ represents thus the form a sheet of water ought to have in flowing through the wheel. The cross section of the wheel is now easily obtained in the manner shown by figures 3, 4 and 5, and the construction of it will easily be understood from these figures. The surface $a_1a_1e_1e_1$—see Fig. 4—is then the surface which is denoted by the letter A, and the surface $a_1a_1d_1d_1$ is that denoted by A_x.

For wheels where the radius r_1 is greater than the radius r_2, the values of B_x that correspond to the values of x, when the values of x are less than the radius r_2, ought to be found from:

$$\frac{B_x}{B_2}=\frac{\xi_2}{\xi_x}\cdot\frac{r_2}{x}\cdot\frac{1}{\sqrt{1+\cot^2\varphi\left\{1-\left(\frac{r_2}{x}\right)^2\right\}}} \quad (56).$$

which is easily obtained, if it is assumed that the velocity of the water has a constant value and that the path of the water is a straight line. How to find this equation will now be shown. In the same way as equation (15) is obtained, it is found that:

$$1=\frac{c_2}{c_2}=\frac{\xi_2}{\xi_x}\cdot\frac{B_2}{B_x}\cdot\frac{\sin\varphi}{\sin\varphi_x}\cdot\frac{r_2}{x}$$

Also is easily found from Fig. 8 that:

$$x\cos\varphi_x=r_2\cos\varphi$$

and then:

$$\sin\varphi_x=\sqrt{1-\left(\frac{r_2}{x}\right)^2\cdot\cos^2\varphi}$$

By use of these equations is the equation (56) obtained.

This equation must be used for all inward flow turbines, because in these wheels the water will increase in its velocity when it leaves the wheel, which gives a loss of efficiency.

The guides in the guide case ought to be made so that the water enters the wheel through the angle α to the periphery at the inlet of the wheel, and the forms of the guides ought thus to be made as involute curves. Such a curve is obtained if a circle with a radius of the value $r_1\sin\alpha$ is drawn, with the center of the wheel as a center, and the involute curve to this circle is constructed, which curve gives the form of the vanes.

The value of ξ at the guide case must be the same as ξ_1 and never less.

GENERAL THEORY FOR TURBINE WHEELS.

The notations used in this theory are the same as in the theory for radial flow turbines, notwithstanding the change of notations in Fig. 9. A turbine of this

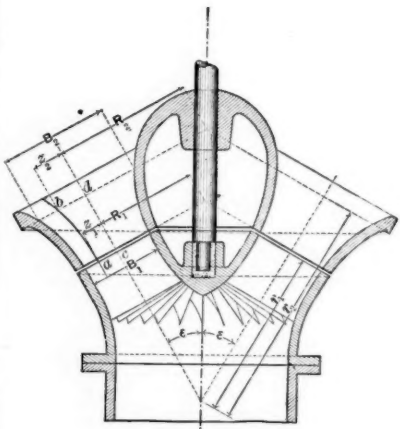

Fig. 9

form is a parallel flow turbine when the angle $\varepsilon=0$, and an outward or inward radial flow turbine when $\varepsilon=90°$. If r_2 is greater than r_1 or less than r_1, then they will be respectively outward and inward flow turbines.

Assume that Fig. 9 represents a turbine in general, and that the sheet of water that enters the wheel at a discharges at b, and that:

$$z_2 = \frac{B_2}{B_1} z_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (57).$$

If the thickness of this sheet of water at a is equal to $\triangle z$ then is its thickness at b $\frac{B_2}{B_1} \triangle z$. In order to calculate these wheels in the easiest way we should assume that:

The normal velocity of the water when it enters the wheel is a constant, and thus the value of $\sqrt{\mu} \sin a$ is also a constant. For one and the same turbine the value of μ must be a constant and thus also the angle a *a constant* value, independent of the value of the distances to the center line of the wheel.

If it is assumed that the line cd is a center line of the cross section of the wheel, then this line divides the distances B_1 and B_2 in two equal parts.

Assume that the value of z_1 is negative if the distance from the point a to the center line of the wheel is less than the distance from the point c to the center line of the wheel. The value of z_2 is positive or negative in the same way.

The proportion between the velocities of the wheel at the points b and a will be denoted by m_z. Then is:

$$m_z = \frac{R_2 + z_2}{R_1 + z_1} \quad . \quad . \quad . \quad . \quad (58).$$

From equations (57) and (58):

$$m_z = \frac{1}{1 + \frac{z_1}{R_1}} \left(\frac{R_2}{R_1} + \frac{B_2}{B_1} \cdot \frac{z_1}{R_1} \right) \quad . \quad . \quad . \quad . \quad (59).$$

If $\varepsilon = 90°$ then the values R_1 and R_2 become infinite and the value of m_z is:

$$m_z = \frac{R_2}{R_1} = \frac{r_2}{r_1} = m$$

which is the value of m for radial flow turbines.

For the sheet of water, that flows through the wheel along the line ab, the equations for radial turbines can be used, if in those equations the value m_z is used instead of m.

When a wheel is to be calculated we at first assume $z_1 = 0$ and then calculate the value of m_z from the equation (59), then by use of the previously given equations for radial turbines the values of β, γ and φ are found. For the sheet of water that enters the wheel at a, the values of β_z γ_z and φ_z are to be found. For the point a the value of m_z is obtained from equation (59). For this point the velocity of the wheel is then:

$$V_z = \frac{R_1 + z_1}{R_1} \cdot V_1$$

$$= \frac{R_1 + z_1}{R_1} \cdot \sqrt{\mu} . \sin a (\cot a + \cot \beta) . c$$

when β is the value of β which is obtained for $z = o$.

Also according to equation (4) is:

$$V_z = \sqrt{\mu} \sin a (\cot a + \cot \beta_z)$$

Thus is obtained that:

$$\cot \beta_z = \frac{R_1 + z_1}{R_1} (\cot a + \cot \beta) - \cot a \; . \quad (60).$$

By use of the previously given equations (28) and (29), or (41) and (42), the values of cot γ_z and cot φ_z are also to be found. By assuming various values for z_1, both positive and negative, the form of every part of the wheel can be found. In practice it is enough to assume only three values of z_1, namely,

$$+\frac{B_1}{2}, \; o \text{ and } -\frac{B_1}{2}.$$

In order to find the relative efficiency of the wheel we must find the values η_z and take their mean. It is easy to find that for the sheet of water, which enters the wheel in the point a, the value η_z is:

$$\eta_z = 1 - \frac{\mu \sin^2 a}{m_z^2} \left(\frac{\xi_1}{\xi_2} \right)^2 \cdot \left(\frac{B_1}{B_2} \right)^2 (1 + \cot^2 \varphi_z)$$

$$\left\{ 1 + \left(\frac{z_1}{r_2 - r_1} \right)^2 \left(\frac{B_2}{B_1} - 1 \right)^2 \frac{1}{1 + \cot^2 a} \right\} . \quad (61).$$

or approximately:

$$\eta_z = 1 - \frac{\mu \sin^2 a}{m_z^2} \left(\frac{\xi_1}{\xi_2} \right)^2 \cdot \left(\frac{B_1}{B_2} \right)^2 (1 + \cot^2 \varphi_z)$$

The efficiency of the wheel is then:

$$\eta = \frac{\Sigma (R_1 + z_1) . \eta_z}{\Sigma (R_1 + z_1)} \quad . \quad . \quad . \quad . \quad (62).$$

If as before asserted only three values $+\frac{B_1}{2}$, o and $-\frac{B_1}{2}$ of z_1 are assumed, then it is found that:

$$\eta = \frac{\left(R_1 + \frac{B_1}{2} \right) . \eta_+ + R_1 . \eta_0 + \left(R_1 - \frac{B_1}{2} \right) \eta_-}{3 . R_1}$$

$$. \quad . \quad . \quad . \quad (63).$$

when η_+, η_0 and η_- are the values of η_z obtained for the values

$$+\frac{B_1}{2},\ o \text{ and } -\frac{B_1}{2} \text{ of } z_1.$$

The dimensions of a turbine wheel are to be found if the power required, the head of water and the least value of η required are known. If N is the number of horse power required, then the volume of water that must be used per second is:

$$Q=\frac{75}{1000}\cdot\frac{N}{H}\cdot\frac{1}{\eta} \quad . \quad . \quad . \quad (64).$$

when meter and kilogram are used, and

$$Q=\frac{550}{62.4}\cdot\frac{N}{H}\cdot\frac{1}{\eta} \quad . \quad . \quad . \quad (64)'$$

when feet and pounds are used.

The value of c, that corresponds to the whole head of water is:

$$c=\sqrt{2g.H} \quad . \quad . \quad . \quad . \quad (13).$$

If the value of $\sqrt{\mu}\sin\alpha$ is assumed to be known, then:

$$2\pi.\frac{r_1.R_1}{\sqrt{r_1^2+R_1^2}}.\xi_1.B_1=\frac{Q}{\sqrt{\mu}\sin\alpha.c} \quad . \quad (65).$$

which equation gives the relation between the values of r_1, R_1 and B_1 and thus the dimensions at the inlet of the wheel.

For a radial flow turbine is then:

$$2\pi\xi_1.B_1r_1=\frac{Q}{\sqrt{\mu}\sin\alpha.c} \quad . \quad . \quad . \quad (66).$$

and for a parallel flow turbine:

$$2\pi\xi_1B_1.R_1=\frac{Q}{\sqrt{\mu}\sin\alpha.c} \quad . \quad . \quad . \quad (67).$$

One more equation may be used to find the dimensions of the wheel, if the value of cot φ is very small:

$$m.\frac{B_2}{B_1}=\frac{\sqrt{\mu}\sin\alpha}{\sqrt{1-\eta}} \quad . \quad . \quad . \quad (68).$$

which value is obtained by approximating equation (24).

In order to make it better understood how to use the equations, the calculations for a wheel, of the form indicated by Fig. 9, will now be given. Calculations of turbines of other forms are to be made in the same way.

Assume that a turbine shall give 160 horse power in order to perform useful work and to overcome the friction in the journals, by an effective head of water of 5 meters, that is to say that the virtually head of the water is diminished by heads that correspond to the losses of efficiency occurred by the friction of the water in the penstock and the wheel, irregular motions and changes of the direction of the water in its flow. The efficiency is to be not less than 80 per cent. of the natural power.

Assume that the water discharges under the lowest surface of the water in the tail race.

Assume that: $\varepsilon=45°$, $\sqrt{\mu}\sin\alpha=\frac{1}{2}$, $\xi_1=0.95$ $\xi_2=90$ and $\frac{B_2}{B_1}=1.2$. From the equation (68) is obtained: $m=0.93$. Assume $m=1.25$, which gives better efficiency.

The volume of water per second is according to equation (64): Q=3 cubic meters. The value of c is from equation (13) found to be: $c=9.91$ meters. Since the angle ε is 45°: $R_2=r_2$ and $R_1=r_1$. From the equation (65) is obtained: $R_1 . B_1 = 0.1435$, and thus if $B_1=\frac{R_1}{2}$: $R_1=0{,}536$ meter. Then is $R_1=536^m/_m$, $R_2=670^m/_m$, $B_1=268^m/_m$, $B_2=322^m/_m$. Assume α of such a value that: cot $\alpha=1{,}5$. From equation (10) is: $\mu=0{,}81$.

If $z=o$ then from equation (59) $m_z=1.25$ which is the value as before assumed. Assume cot $\varphi=o$, then is found from equation (48): cot $\gamma=2.37$. From equation (40): cot $\beta=-0.167$. From equation (30) $\frac{V_1}{c}=1.33$. The value of n is:

$$n=\frac{30}{\pi}\cdot\frac{V_1}{r_1}\sqrt{1+\cot^2\varepsilon}$$

$$n=\frac{30}{\pi}\cdot\frac{c}{r_1}\sqrt{\mu}.\sin\alpha(\cot\alpha+\cot\beta).\sqrt{1+\cot^2\varepsilon} \quad . \quad . \quad . \quad . \quad (69).$$

because the distance of the point c to the center line of the wheel is: $r_1.\sin\varepsilon$.

Then is: $n=333$. From equation (61) $\eta_0=0.876$.

If $z=+134^m/_m$ then from equation (59): $m_z=1.24$. From equation (60): cot $\beta_z=0.167$. From equation (41): cot $\varphi=-0.341$. From equation (42): cot $\gamma=2{,}57$. From equation (61): $\eta_+0\,858$.

If $z=-134^m/_m$ then from equation (59): $m_z=1.27$. From equation (60): cot $\beta_z=-0.50$. From equation (41):

$\cot\varphi = 0.568$. From equation (42): $\cot\gamma = 2.40$. From equation (61): $\eta_- = 0.839$. From equation (63) the efficiency of the wheel is found to be $\eta = 0.859$.

In order to review the relations between different turbines, the following tables were made for turbines constructed in such a way, that the discharge is under the lowest surface of the water in the tail race. For turbines, where the discharge is in the air, there are about the same relations between different turbines. For these wheels the value of γ is some greater.

TABLES FOR RADIAL FLOW TURBINES.

	$\sqrt{\mu}\sin a$.	m.	$\cot a$.	μ.	$\frac{B_2}{B_1}$.	$\cot\varphi$.	$\cot\gamma$.	$\cot\beta$.	$\frac{V_1}{c}$.	η.
1*)	½	1.20	0.00	0.25	0.94	0.78	4.00	2.39	1.20	0.688
2	"	"	"	"	1.00	0.94	"	2.12	1.06	0.672
3*)*)	"	"	"	"	1.18	2.00	"	1.18	0.59	0.370
4	"	1.00	"	"	1.00	0.59	"	3.41	1.71	0.664
5*)	"	"	"	"	1.12	0.78	"	2.88	1.44	0.678
6*)*)	"	"	"	"	1.41	2.00	"	1.41	0.71	0.339
7	"	0.85	"	"	1.00	0.40	"	4.98	2.49	0.598
8*)	"	"	"	"	1.32	0.77	"	3.39	1.69	0.669
9*)*)	"	"	"	"	1.65	2.00	"	1.68	0.84	0.275
10*)	½	"	"	0.11	0.88	0.78	"	5.07	1.69	0.679
11	"	"	"	"	1.00	1.14	"	3.97	1.32	0.648
12*)*)	"	"	"	"	1.11	2.00	"	2.50	0.83	0.374
13	½	1.2	0.50	0.31	1.00	0.00	5.76	3.50	2.00	0.827
14	½	1.20	0.50	0.31	1.50	0.00	8.64	3.50	2.00	0.918
15	"	"	"	"	1.00	0.27	4.00	2.09	1.29	0.813
16	"	"	"	"	0.69	0.00	4.00	3.50	2.00	0.638
17	"	"	1.00	0.50	1.00	"	2.88	1.00	1.00	0.827
18	"	"	"	"	1.50	"	4.32	1.00	1.00	0.920
19	"	"	1.73	1.00	1.00	"	1.66	−0.58	0.58	0.827
20	"	"	"	"	1.50	"	2.49	−0.58	0.58	0.923
21	"	1.00	0.50	0.31	1.00	"	4.00	3.50	2.00	0.750
22	"	"	"	"	1.50	"	6.00	3.50	2.00	0.882
23	"	"	1.00	0.50	1.00	"	2.00	1.00	1.00	0.750
24	"	"	"	"	1.50	"	3.00	1.00	1.00	0.885
25	"	"	1.73	1.00	1.00	"	1.16	−0.58	0.58	0.750
26	"	"	"	"	1.50	"	1.73	−0.58	0.58	0.887
27	"	0.85	0.50	0.31	1.00	"	2.89	3.50	2.00	0.654
28	"	"	"	"	1.50	"	4.33	3.50	2.00	0.836
29	"	"	1.00	0.50	1.00	"	1.45	1.00	1.00	0.654
30	"	"	"	"	1.50	"	2.17	1.00	1.00	0.840
31	"	"	1.73	1.00	1.00	"	0.83	−0.58	0.58	0.654
32	"	"	"	"	1.50	"	1.25	−0.58	0.58	0.843
33	⅓	"	0.50	0.14	1.00	"	6.50	8.50	3.00	0.846
34	"	"	"	"	1.50	"	9.75	8.50	3.00	0.927
35	"	"	1.00	0.22	1.00	"	3.25	3.50	1.50	0.846
36	"	"	"	"	1.50	"	4.88	3.50	1.50	0.929
37	"	"	2.83	1.00	1.00	"	1.15	−1.24	0.53	0.846
38	"	"	"	"	1.50	"	1.72	−1.24	0.53	0.930
39	½	1.10	1.73	1.00	1.00	"	1.40	−0.58	0.58	0.793
40	"	"	"	"	1.50	"	2.10	−0.58	0.58	0.906
41	1.00	2.00	0.00	1.00	1.00	0.52	4.40	0.97	0.97	0.684
42*)	"	"	"	"	1.20	0.80	"	0.75	0.75	0.715
43	"	"	"	"	1.50	1.58	"	0.47	0.47	0.613
44*)	½	"	"	0.25	0.60	0.80	"	1.50	0.75	0.714
45*)*)	"	"	"	"	0.78	2.20	"	0.71	0.35	0.385

For the wheels 1—40 is assumed that $\frac{r_2 - r_1}{B_1} = 1$ and for 41—45 $\frac{r_2 - r_1}{B_1} = 3$. The equations marked with *) are calculated by use of equation (46) and those marked with *) *) are calculated under assuming of the maximum value for $\cot\varphi$. For all wheels is assumed that $\xi_1 = \xi_2$.

TABLES FOR PARALLEL FLOW TURBINES.

	z_1	$\sqrt{\mu}\sin a.$	$\cot a$	$\mu.$	$\frac{B_2}{B_1}$	$\cot \varphi.$	$\cot \gamma.$	$\cot \beta.$	$\frac{V_1}{c}$	η_z	$\eta.$
1.	$+\frac{B_1}{2}$	$\frac{1}{2}$	0.00	0.25	1.00	0.44	5.00	4.55		0.702	
	0	"	"	"	"	0.59	4.00	3.41	1.71	0.664	0.654
	$-\frac{B_1}{2}$	"	"	"	"	0.88	3.16	2.28		0.577	
2.	$+\frac{B_1}{2}$	$\frac{1}{2}$	0.50	0.50	1.00	−0.13	5.21	4.83		0.746	
	0	"	"	"	"	0.00	4.00	3.50	2.0	0.750	0.745
	$-\frac{B_1}{2}$	"	"	"	"	0.25	2.92	2.17		0.737	
3.	$+\frac{B_1}{2}$	$\frac{1}{2}$	1.73	1.00	1.00	−0.43	1.11	−0.19		0.703	
	0	"	"	"	"	0.00	1.16	−0.58	0.58	0.750	0.688
	$-\frac{B_1}{2}$	"	"	"	"	0.86	1.63	−0.96		0.566	

For these three turbines it is assumed that $B_1=\frac{2}{3}R_1$. For all wheels it is assumed that $\xi_1=\xi_2$.

Fig. 3 represents the turbine No. 20, and Fig. 8 the turbine No. 42. The turbine Fig. 8, is constructed under the unfavorable assumptions of $\sqrt{\mu}\sin a=1$ and $a=90°$; but by using the value of m as high as 2, this wheel will give an efficiency of 71 per cent. of the natural power.

The turbine theory above considered is believed to be totally unlike all theories hitherto used. By assuming the value of the normal velocity of the water at the inlet of the wheel, as the first requisite for further calculations, the theory is made very simple, and an exact theory could be made for turbines in general. By using the values cotangents instead of the angles a theory is obtained, which does not require the use of trigonometrical tables, as there is no need of knowing the values of the angles. To determine the angles by use of the cotangents is very easy. Turbines in general have never had, to the knowledge of the writer, any theory. Also the way to find the form of the vanes is unlike other methods. To my knowledge there has never been any exact theory for turbines in use, and therefore it is hoped that the theory now published will be found of help to those who wish to make good turbines.

SNOW CLEARING IN TURIN.

By SIGNORI PECCO and PRINETTI.

From "L'Ingegneria Civile," for Abstracts of the Institution of Civil Engineers.

TURIN and its suburbs are divided into three districts for this purpose, of which two are urban, comprising all the paved roads, and one district is suburban, comprising all communal roads. Each district is subdivided into sections varying in number from five to eight. The work is done by petty contractors, who find labor, horses and carts, and is paid for at a price per centimeter of snow fallen. The city provides tools. The street sweepers are also employed at intersection of main streets and other important points, and to sprinkle sawdust, &c., on the roads.

The snow is first thrown up in heaps, and then thrown into the sewers, rivers and canals, or stacked in special places. The sewers are flushed from a canal in the upper part of the city.

Several mechanical methods of melting the snow have been investigated with the following results: Garneri's Tube Calorifer consists of a galvanized iron pipe, with a fire at one end and a fan for drawing hot air through it at the other. The snow is heaped round the tube. The cost amounted to 2⅓d. per cubic yard (without reckoning the cost of the apparatus), as against 1d. per cubic yard for clearing away in the usual manner. The pyro-hydro-melting plough was a machine proposed by Garneri for melting the snow *in situ*, but did not seem worth trying. Nawckins and Mullaly's (New York) snow melter consists of a boiler from which a mixture of steam with the gaseous products of combustion issues in one or more jets upon the snow. The cost for fuel alone would be ¾d. per cubic yard of snow melted, to which must be added interest and sinking fund for machine costing £1,280. Bouvet's system resembles the tube calorifer, but the tube is pierced with small holes from which steam issues. Melting by salt.—It has been found in Paris that 0.36 lbs. of salt is required to melt a frozen stratum 1 yard square and 1½ to 2 inches thick. The price of salt in Turin being 2.4d. per lb., the cost would amount to 16d. per cubic yard. Wells as receptacles for snow.—It not being thought advisable to try any of the above systems, it was proposed that a well should be dug to receive the snow from one contract. The subsoil of the city is gravel, through which a large body of water passes. A well, 16 feet 6 inches diameter, 42 feet 6 inches deep, amply sufficed in 1880–81 to receive the snow from an area of 13,150 square yards. This system is rapid and economical where the cost of cartage exceeds ¾d. per cubic yard.

The area from which the snow was removed in 1880–81 was 2,800,000 square yards; the total depth of snow was 1.41 foot. There were one hundred and twenty-one contractors. The number of men sometimes amounts to four thousand (besides the regular sweepers), and five hundred carts. On January 19th, 1881, three thousand six hundred and eighty-four men and four hundred and seventy-five one-horse carts were employed to clear away a depth of 0.46 foot of snow. The average cost for clearing and carting a cubic yard is 0.93d. in districts 1 and 2. In district 3, where it is only heaped up, it is 0.4d. In addition to these amounts paid by the contractors there is the cost of providing and maintaining tools, and the charge for canals, &c.; these items, with superintendence, add from 20 to 25 per cent. to the cost. The total cost per inch depth of snow is £274.

The tramway companies have to bear their share of the cost, and pay for clearing a width of 9 feet 10 inches for single and 19 feet 8 inches for double line. For a length of 17½ miles of tramway the cost is £12 11s. per inch depth of snow.

The question of letting the work to one or two large contractors has been considered by the authorities, but the present arrangement is thought to be the best. In the event of dispute with a large contractor the snow would be left lying in the street, while the men now employed can be dismissed at a moment's notice and readily replaced, and they are satisfied with a lower rate of pay than a contractor would demand, who provided his own tools, and was required to have large gangs of men always available, with the possibility of having no work for them throughout the winter. The superintending staff consists of twenty engineers and assistants, who take great interest in the work, which involves much responsibility in cases of emergency. In the busiest parts of the city the snow is heaped up by 9 A.M., when the depth does not exceed 6 inches, and is cleared away within twenty-four hours. In all the inhabited parts the heaping up is done in one day and the removal in two days more. A copy of the regulations for the contractors is added, and also a table showing the surface cleared, the total depth of snow and the total cost for each year from 1859–50 to 1880–81. From this it appears that the area has increased from 1,273,000 square yards to 2,803,000 square yards; that the depth has varied from 1¼ inch to 36½ inches; and the cost from £240 to £7,040. There is also a list of tools, carts, &c., kept in store for this service.

A DYNAMO-ELECTRIC machine has been designed by Dr. Paget Higgs in which the armature is almost completely encircled by tubular ring magnets.

THE INSTITUTION OF CIVIL ENGINEERS.

INAUGURAL ADDRESS OF THE PRESIDENT, SIR W. G. ARMSTRONG, C.B., F.R.S.

From "The Engineer."

He observed that it had been the practice of his predecessors in the chair, to select topics for their address that had reference to branches of engineering which operated to increase the productiveness of human industry, and there were many who would contend that all engineering efforts ought to center upon that object. It might be fully admitted that the general amelioration of the material condition of the world was the noblest object of engineering science; and if men and nations ceased to be bellicose and rapacious, such would naturally be the direction which all engineering practice would take; but this was a world of contention, where no individual state could insure its independence, and carry on its industrial occupations in safety, without protecting itself against the possible aggression of its neighbors. Thus it was that the science of the engineer was invoked for the purposes of war as well as for those of peace; and it was probable that the engineering element would, in future, enter more and more largely into the operations of war, until the issue would be chiefly dependent upon the superiority of mechanical resource, displayed by one or other of the contending parties. There was no country in the world less disposed to be aggressive than our own, but there was none so likely to incite the greed of an assailant, or so vulnerable in relation to its commerce. War indemnities had degenerated into mere exactions proportioned to the wealth of the vanquished; and England, being the richest of nations, offered the highest premium for successful attack. As to commerce, England had more than one-half of the ocean carrying trade of the whole world in her hands, and her ships, swarming over every sea and conveying merchandise of enormous value, would, in the event of war, invite the depredations of hostile crusiers. We had seen in recent years what ravages a single-armed ship could inflict upon a mercantile navy incomparably smaller than our own, and, in our case, it was not only property, but indispensable food that was at stake. The ever-increasing population of Great Britain had already far outgrown its internal means of support, while the increasing cheapness of imported food so discouraged native agriculture that we might expect our future dependence upon foreign supply to increase even more rapidly than our population. This was not the occasion to discuss either moral questions affecting war, or political questions concerning free trade. We had the stern fact before us that national defence was in our case peculiarly a necessity, and the question how it could best be effected, from an engineer's point of view, was a legitimate subject for this address.

England must always be chiefly dependent for security upon her naval power, but we could not hope that she would ever again be so dominant at sea as before the introduction of steam navigation. So long as naval superiority depended upon seamanship and an unlimited supply of sailors, no nation or combination of nations could compete with us; but as soon as it became established that fighting ships could be maneuvered with more certainty and precision by the power of steam than by the power of wind, a revolution began which had gradually made naval warfare a matter of engineering rather than of seamanship. The introduction of rifled ordnance and percussion shells was the second step in this revolution, and had the effect of condemning as useless the whole fleet of wooden ships with which all our victories had been won, and which were the pride of the nation. Then commenced that contest between guns and armor which had gone on to this day, and had not yet been decided. Nor would it, in all probability, ever be decided, seeing what an *ignis fatuus* finality was. The most recent stage of this revolution was that marked by the

introduction of torpedoes, against which our ponderous ironclads were no more secure than ships of thinnest iron. These constantly-changing phases of attack and defence had placed our naval authorities under extreme difficulty in deciding upon questions of ships and armament. To stand still was impossible, while to act upon uncertain data was sure to lead to mistake. The necessary consequence had been that types and patterns of ships had been continually changing, and vessels, costing vast sums of money, had become nearly obsolete almost as soon as made. We could not wonder that, so long as invulnerability was conceived to be attainable, great sacrifice should be made for its accomplishment; but with our present knowledge, which it would be unfair to apply to a criticism of the past, we might feel assured that invulnerability was a chimera. Not only did we see that armor was unavailing against torpedo attack and ramming, but we were justified in concluding that every attempt to increase resistance to projectiles would be quickly followed by a coresponding increase in the power of artillery. Our early ironclads, like the Warrior, were plated all over with armor 4½ in. thick—a thickness which could now be pierced with field pieces. To resist the most powerful guns now afloat, armor of at least 2 ft. in thickness was required; and in order to reconcile the constantly-increasing thickness with the weight which the ship was capable of carrying, it had been necessary to restrict the area of armored surface to ever narrowing limits, leaving a large portion of the ship without protection. In those magnificent and tremendous vessels which the Italians were now building, the armor would be withdrawn from every part except the battery, where guns of 100 tons would be placed, and where the armor would be confined to a narrow belt of great thickness. Everything of importance that projectiles could destroy would be kept below water level, and, so far as artillery fire was concerned, the ships would be secured against sinking by means of an under-water deck and ample division into compartments. Armor therefore seemed gradually contracting to the vanishing point; but, until it actually disappeared, it was probable that no better application of it could be made than had been decided upon by the acute and enterprising naval authorities of Italy for the great ships they were now constructing.

The dread of the terrible effects of the fragments of shells bursting amidst a crowded crew, and the apprehension that the smoke from the explosion, when it occurred between decks, would paralyze the service of the guns, had conduced more than anything else to the adoption of armor. Methods of avoiding or lessening these dangers, otherwise than by the use of armor, had been little considered; yet the alarming aspect of the case was greatly altered, when we reflected that, by the application of mechanical power, to do what had hitherto been done by a multitude of hands, the exposure of a crowded crew could be avoided, and also that the guns might all be mounted on an open deck, where the smoke from shells would speedily clear away.

As to the comparative liability of an ironclad and an unarmored ship to be sunk by projectiles, there was much less difference between them than was generally supposed; because the unarmored ship, though freely penetrable, might be so constructed that the entrance of water by perforation could not extensively flood the ship, unless it took place at a great number of critical places. Indeed, by introducing an under-water deck, with divisional spaces, and by the partial application of cork, as in the Inflexible, for displacing influent water, and thereby preserving stability, and also by a proper distribution of coal for the same purpose, an unarmored ship might be rendered almost incapable of being sunk; and it was rather surprising that so little attention had been directed to the attainment of that object.

It was not too much to say that, for the cost of one ironclad we could have three unarmored ships of far higher speed, and carrying collectively three armaments, each equal to that of the armored vessel. It might be asked, Which would be the better investment? If it were imagined that the three were matched in combat against the one, it would be perceived that, in addition to their numerical superiority, the former would possess many advantages. Being

smaller they would be more difficult to hit. Being swifter they could choose their positions and be free to attack or retreat at pleasure. Being more nimble in turning they would be better adapted both for ramming and for evading the ram of their adversary. Finally, the conditions of superior speed and agility would favor their use of torpedoes and submarine projectiles; although it was a question whether, for the sake of a much needed simplification, it would not be better to confine that species of attack to separate vessels specially constructed for that one particular purpose. Even if the utmost advantage she could possess were conceded to the ironclad, viz., that of being impenetrable by the guns of her opponents, she could not prevail in a contest of three against one, unless by the use of securely-protected artillery she could keep her assailants at bay, and gradually destroy them by her fire if they persisted in their attack. Such might be the issue if the allied vessels had nothing but guns to oppose to guns; but they would, naturally, under such circumstances, place their men below, out of the reach of projectiles, and then attack with their rams or torpedoes. With the crews in safety, it was scarcely possible that unarmored vessels, with under-water decks and all their machinery beneath, should suffer any disabling injury by being pierced in a few places by either shot or shell. But take the much more probable alternative of the armored vessel being penetrable by the guns which would be used against her. In that case her enemies might elect to make the contest one of artillery. On their part, armor-piercing projectiles would be used, which, on penetrating the thick sides of the ironclad, would carry inboard a mass of broken material far larger in quantity than the fragments of the shells with which they would be assailed, and quite as destructive in effect. The ironclad would have to sustain the converging fire of three ships, each carrying the same armament as her own, and her swift and nimble adversaries would steam round and round her, directing their fire on the most vulnerable points, and ever ready to seize a favorable moment to dash in and finish the contest by ramming. In either case, therefore, the ironclad would be over-matched by a combination of unarmored vessels representing the same pecuniary value. Without entering into technical questions concerning fleet fighting, it seemed reasonable to believe that the result would be the same if the number engaged on each side were proportionately multiplied. Inferiority of speed and of number would still give the choice of position, and secure the advantage of converging fire, besides with the greater power of division and of concentration must always belong to the more numerous fleet. But if ironclads were not needed for the purpose of opposing ironclads it was difficult to see for what purpose they were wanted at all. For every other kind of service a numerous fleet of smaller and swifter vessels, unencumbered with armour, would clearly be preferable. To protect our commerce, to guard our extensive seaboard against invading flotillas, to lend naval assistance to our colonies, in case of need, and generally to maintain our supremacy at sea, we required a far more numerous navy than we possessed or could afford to possess unless we vastly reduced our expenditure on individual ships, and to do this we must dispense with armor. It might, perhaps, be rash entirely to abandon armor, so long as other nations continued to use it, because nothing but the experince of an actual war would remove all question as to its possible utility; but considering the indisputable value of a numerous fleet of swift and powerfully-armed ships, built with a view of obtaining the maximum amount of unarmored defence, and considering that such vessels, unlike armor clads, could never grow much out of date, it did seem to be expedient that the chief expenditure of this country should be upon ships of that description. Lightness should be the special aim in the construction of such vessels. Steel plates should be used for the hulls, and guns and engines should be of the least possible weight consistent with the necessary power. Every ton of weight saved would enable higher speed to be attained, and there was probably no quality in a flying ship which would so much develop in importance as that of swiftness. Messrs. Thornycroft has led the way in showing what extraordinary speed could be realized in diminutive

vessels, by reducing to the utmost the weight of every part of the structure and its contents; and although we could not expect to attain proportionate speed by the same method in ocean-going ships of war, yet there could be no question that we might have far swifter ships than at present if lightness were made the principal object, instead of the prevalent practice of loading ships with cumbrous armor, in the vain hope of rendering them invulnerable. Light unarmored ships, designed by Mr. George Rendel, had lately been built in this country for foreign powers, which, with a displacement of only 1,300 tons, had attained a speed of 16 knots an hour. They carried coal for steaming 4,000 miles, and had already actually steamed 3,500 miles without replenishing. They were each armed with two 10 in. new-type guns, which had nearly an all-round fire, and were capable of piercing 18 in. of iron armor; and with four 40 pounders on the broadsides. It was a very serious question what could be done in the event of a number of such vessels as these being let loose upon our commerce. At present there was not a single ship in the British navy carrying an armament competent to engage them, that could overtake them in pursuit, or evade their attack when prudence dictated a retreat. Confidence was often expressed in our mercantile marine being capable of furnishing, on an emergency, a supply of vessels fit to be converted into cruisers; but where were there to be found amongst trading or passenger steamers, vessels possessing a speed of 16 knots, with engines and boilers below water level, and having an under-water deck to save them from sinking when penetrated by projectiles at or below the water line. From his own experience he knew how difficult it was to adapt mercantile vessels to the purposes of war, and how unsatisfactory they were when the best had been made of them. It was alarming to think how unprepared we were to repress the ravages which even a small number of swift marauding vessels, properly constructed and armed for their purpose, could inflict upon the enormous property we had at all times afloat, and how little we could hope to clear the sea of such destructive enemies, by cruisers improvised out of ready-made steamers destitute of all the conditions necessary to render them efficient for such a service. It must ever be borne in mind that it was not merely the loss of property and interruption of trade that we had to fear, but also the interception of food supplies; and that the more our population increased and our agriculture declined, the more terribly effective for reducing us to submission, would be the stoppage of those supplies.

The President then adverted to harbor defence. He pointed out that many of our ironclad forts had already outlived the stage of artillery progress for which they were adapted. He expressed his opinion as to the best method of rendering large guns effective in shore batteries. He dwelt upon the value of gunboats, considered as floating gun carriages, and used in combination with torpedo craft and submarine mines; all of which, he suggested, might be committed to the management of trained naval and engineer volunteers resident on the spot.

He said it would be a grand development of the volunteer movement, of which this country was so justly proud, if it were thus to be extended to harbor defence; and he was informed that, so far as the use of submerged torpedoes was concerned, a project of intrusting their employment to a corps of volunteer engineers was already under consideration. The superior education and intelligence of the class from which our volunteers were mostly supplied would especially fit them for the discharge of duties involving skill and discretion, such as would be required in the handling of electrical apparatus, and we might be sure that, wherever dash was needed in the use of torpedo boats, there would be no lack of that quality amongst volunteers in the hour of trial.

On the subject of artillery, he described the progress of gun manufacture since the introduction of rifled ordnance, prior to which a gun was simply a tube of cast iron or bronze closed at one end. He also discussed the question, what, under the present conditions and prospects of steel manufacture, should be our practice as to the use of that material for artillery purposes. He was then led to speak of a system of construction which

had not passed through the experimental stage, but which, from the results it had already given, promised to attain a wide application. He referred to that system in which the coils surrounding the central tube consisted of steel wire, or ribbons of steel, wound spirally upon the tube. To those who objected to welded coil tubes on the ground of supposed deficiency of longitudinal strength, this mode of construction must appear especially faulty, inasmuch as lateral adhesion, instead of being, as contended, merely deficient, was altogether absent; while to those who advocated the present coil system, this variety must commend itself as affording the greatest possible amount of circumferential strength that could be realized from the material employed. Steel in the form of wire or drawn ribbon, possessed far greater tenacity, and also greater toughness, than in any other condition, and in applying it to guns there was perfect command of the tension with which each layer was laid on. He then alluded to the labor of those who had worked in this direction, and referred to a 6-in. breech-loading gun of this construction made at Elswick, and tried in the beginning of 1880. He stated that the charges used with it were large beyond precedent, and the energies developed proportionately high. Being satisfied with the results obtained with this gun, a second one of larger dimensions had been commenced, and was now finished. Its caliber was 26 centimeters or about 10¼ in. Its length was 29 calibres, and its weight was 21 tons. In the previous gun he depended for end strength upon the thickness of barrel only; but in the new one, layers of longitudinal ribbons were interposed between the coils, in the proportion of one longitudinal layer to four circular layers. The longitudinals were secured to the trunnion ring at one end and to a breech ring at the other, and were in themselves calculated as sufficient to resist the end strain on the breech, independently of the strength afforded by the tube. The whole was encased in hoops shrunk upon the exterior of the coil, for the treble purpose of protection from injury, of preventing slipping in the event of the failure of an external strand, and of adding to the strength of the gun. This gun had already been tried, and had given results which, in relation to its weight, were unexampled except by its 6-in. predecessor. Various attempts had also been made abroad to reduce this system to practice, and it was understood that the French were at present engaged in making experimental guns upon the same general principle. With regard to the ribbon form of section, he preferred it to a square section of equal area, as being more favorable for bending over a cylinder, but any rectangular form was better than round wire, on account of the flat bedding surfaces it afforded.

He then discussed the subject of breech loading and muzzle loading, and the various forms of rifling. He also described the many changes that had been found necessary in the form and manufacture of powder for heavy ordnance, and the difficulties which still remained to be overcome.

As to the mounting of guns in forts and ships, he remarked that the difficulties of the problem were much greater than was commonly supposed. It was certain that machinery could no longer be dispensed with for working the guns, and that engine power must be used to economize labor and avoid exposure of the men. In the days of cast iron smooth bores, the heaviest naval gun weighed 95 cwt., and it was deemed impracticable to exceed that limit in a ship. At the present time the heaviest naval gun in the British service was 80 tons, and guns of 100 tons were carried in Italian ships. Instead of projectiles weighing as a maximum 94 lbs., and charges of 16 lbs., we had now to handle projectiles of 1,500 lbs. and charges of 450 lbs.; and to keep pace with foreign navies those limits of weight must be greatly exceeded. Even if it were possible to deal with guns and ammunition of such weights by manual labor, the multitude of men required for the purpose would be greater than could find standing room at the guns. Up to a certain point hand power might be so aided by machinery as to enable larger guns to be worked by men than was formerly deemed possible; but the mechanism required to render hand labor available was quite as liable to be disabled by an enemy's fire as that which would be applied in connection with engine power. There was therefore no reason in this

respect for employing a numerous gun crew in preference to inanimate power. Automatic methods of running out the gun, by which the gun was lifted in recoiling by slides or radius bars and recovered its position by gravitation, might in many cases be advantageously used to save labor, but in a ship the varying inclination of the deck interfered with uniformity of action. The upward motion of the gun also involved the objection of a higher port, and it added greatly to the downward shock, which became very severe on the deck where the guns were large and were fired at considerable elevation with such heavy charges as were now usual. Steam power, acting through the medium of hydraulic pressure, was already largely applied in recent ships for effecting all the operations of working the guns, and where such power was used there was nothing to gain by automatic action for returning the gun into firing position. In considering these various mechanical arrangements now applicable to naval warfare, we perceived the growth of the engineering element in our ships of war, and the importance of mechanical, as well as nautical, acquirements on the part of the officers, as also, in a less degree, on that of the men. Breech-loading guns, carriages fitted with all modern appliances, shot and powder lifts, mechanical rammers and torpedo apparatus, all combined with steam or hydraulic machinery, or with both, constituted mechanisms requiring to be supervised by officers qualified as engineers, and to be handled by men trained in the use of machinery.

Before drawing to a conclusion he would advert to a subject of grave national importance. Our Navy was at present armed with guns which could not be expected to contend successfully with the best modern guns that could be used against them. Happily, most of the older ships of foreign powers were in the same predicament; but all their new vessels, and some of their older ones, were being armed with artillery which, weight for weight, was far superior in power to that of our Navy. Our service guns had simply been overtaken in that rapid progress of artillery which had been going on for the last eight or ten years; and it might be doubted whether any partial remodeling during that period would have averted the present need of re-armament; while it would certainly have involved great sacrifice and confusion of ammunition and stores. But a new departure could not longer be delayed. An irresistible demand had arisen for breech-loading guns, and it was imperative to combine, with the introduction of that system, such other modifications of construction as would realize the increase of power which we now know to be attainable.

It might, however, be asked, What better prospects of finality there was now than we had ten years ago? As to absolute finality, it would probably never be reached, but the country might take some comfort in the reflection that every stage of progress narrowed the field for further development. There was already no substantial room for improvement in the accuracy of guns; and as to power, we were nearly approaching the limit at which severity of recoil and extravagant length of gun would prohibit further advance. We might go on building larger guns almost without limit, though he doubted the policy of so doing, but mere increase of size did not revolutionize system. There seemed, therefore, to be more hope of permanency now than at any former period; but whether this were so or not, we could not, with danger, remain passive.

What, then, should our Government do in regard to the great work of re-arming the fleet? He took it for granted that all new ships would be armed with the best guns that could now be made, and that the more important of the older vessels would speedily receive the same advantage; but beyond this, so long as experience of novelties was deficient, it was a case of cautious procedure. In the mean time, no expense should be spared in judicious experiments, seeing that the expense of experiments was trifling in comparison with that of mistakes. Above all, the Government should pursue such a course as would bring into full play the abundant engineering resources of this highly mechanical country, for increasing the efficacy of our National defences.

THE vicar of Dudley contemplates the use of the electric light in the parish church.

ON THE INSUFFICIENCY OF RESERVOIRS FOR DIMINISHING THE DANGER OF FLOODS.

By M. GROS.

From "Annales des Ponts et Chaussees," for Abstracts of Institution of Civil Engineers.

THE utility of reservoirs in diminishing damage from floods was taken into consideration in France, after the inundations of 1856. Investigations were made in the valleys of the Seine, the Rhone, the Loire, the Garonne, and other important rivers, and resulted in the decision not to carry out the numerous reservoirs which had been proposed, owing to the uncertainty and doubtful efficacy of their action on floods.

Similar investigations were made on these rivers after the inundations of 1875. These latter observations showed, in the case of the Garonne, that a reservoir capacity of 720,000,000 cubic yards would be required to protect Toulouse from a similar flood, and two or three times larger to protect Agen and the rest of the basin. The Saint-Ferréol reservoir, supplying the Canal Du Midi, which has been cited as a specimen of the reservoirs that should be constructed, has only a capacity of under 8,000,000 cubic yards, so that a very great number of similar reservoirs would be required for protecting effectually the basin of the Garonne. The capacity, however, of the reservoirs which would be of value in reducing the height of floods, and could be constructed in the upper valley of the Garonne, would amount to only one-sixth of that required for protecting Toulouse. The investigations led to similar conclusions in the case of the lower Garonne, and of the other principal river basins of France.

The distribution of rain and advantages of situation would oblige the reservoirs to be placed as much as possible in the hilly portion of the basins, where, however, owing to the declivity, the reservoirs would be smaller, and would be liable to be rapidly filled up with detritus. It might also sometimes happen that a flood would be produced by a heavy rainfall in the lower part of a river valley, as was the case in the great flood of the Garonne in 1875, and then the reservoirs in the hills would be useless.

The action, moreover, of reservoirs on the river further down, with an increasing discharge, becomes rapidly less. Thus a lowering of the Rhone at Lyons of $3\frac{1}{4}$ feet, by means of reservoirs above, would amount to only $1\frac{1}{3}$ foot below the confluence of the Saône, and to only 8 inches below the confluence of the Isere at Valence. In like manner a retention of 130,000,000 cubic yards on the Garonne at Toulouse would only act like a retention of 65,000,000 at the mouth of the Tarn, of only 52,000,000 at Agen, and of only 23,000,000 at Tonneins, and its effect would become insignificant at Langon. This shows how large the reservoirs in the upper valleys would have to be made to produce an adequate effect in the lower portions of the rivers. Reservoirs on tributaries, by retarding a flood, would modify the flow in the main river in a variety of ways, which could hardly be determined beforehand, and might be injurious by causing a coincidence of floods.

Often continuous floods are produced by the coming down of several high floods at short intervals apart. Thus the inundation of the valley of the Garonne in 1856 was caused by five successive floods, keeping the river in flood for more than two months. Under such circumstances the reservoirs would be filled by the first flood, and would not be available for lowering the subsequent floods. The reservoir embankments might be endangered by the flow of water over them, and a failure of an embankment might entail more disasters than a very high flood.

It has been proposed that flood reservoirs should be also utilized for supplying canals, for irrigation and water power, thus serving a double purpose. Flood reservoirs, however, to be useful against floods, must be kept empty throughout the whole season when floods may occur. Storage reservoirs have

small outlets, and a flood discharge would have to flow over the embankment or over a wide overfall weir. Such an arrangement might be adopted in a rocky valley, and where the discharge of a river is small; whilst the erection of high embankments across the lower valleys, where the discharge is large and the ground liable to be eroded by the fall of the water, would be dangerous.

The system of reservoirs for providing against floods must accordingly be entirely abandoned, not only on account of the excessive expense and difficulty of obtaining adequate capacity, but also because a carefully designed system of reservoirs along a river valley, which might provide against a flood occurring under definite conditions, would be totally inadequate to cope with all the various combinations of distribution of rainfall and floods of tributaries, by which floods are produced in the main river.

THE LAW OF GEOTHERMIC PROGRESSION.

By P. VAN DIJK.

From "Revue Universelle des Mines." Translated for Institution of Civil Engineers.

UNDER this general title, employed to signify the relation which the subterranean temperature of the earth bears to the depth below its surface, the author investigates first the theoretical transmission of the central heat outwards through the earth's solid crust, from its highly heated core in a state of ignition or fusion; and secondly the inverse transmission of external cold inwards. The expression "geothermic scale" (German *geothermische Tiefenstufe*, and French *échelon géothermique*) being taken to denote, at any distance below the earth's surface, the additional depth which at that point corresponds with a rise of 1° in temperature, he shows that the geothermic scale will increase, according to the first mode of investigation, with increasing distance outwards from the hot core; and, according to the second mode, with increasing depth below the surface.

The outward transmission of central heat is amenable to theoretical investigation alone, as regards that portion of its vast range which is by far the largest, and in which its effects would be by far the most noticeable; and it is only at the remotest extremity of its range, within the comparatively insignificant depths accessible from the earth's surface, that deductions from this theory can be confronted with observed facts. The results of the equations arrived at by the author for the outward transmision of central heat, representing curves of hyperbolic character, would be a practically uniform geothermic scale throughout the greatest depth accessible; while, even if the observed temperature continued appreciably constant down to that depth from the surface, instead of increasing with the depth, such a condition would not preclude the existence of a fused or fiery core. Moreover, if the earth were entirely solid to its very center, the temperature at that point would then have to be infinitely high.

The inward penetration of external cold, on the other hand, admits at once of investigation by theoretical and by practical methods; and it is within the most effective portion of its range, namely, down to the depths accessible from the earth's surface, that deductions arrived at from this theory can be verified or corrected by observations made in sinkings, which have been executed to various depths in different parts of the world. The available observations employed for this purpose, by the author, are collected by him into the accompanying table. The data obtained from the bore holes in the island of Java are the results of observations made by M. Ermeling, engineer officer, by M. Hooze, mining engineer, and by the author himself, who is mining engineer-in-chief in the Dutch East Indies. The data from the Sperenberg bore hole have previously been quoted; others are taken from Naumann.

A glance at the concluding column of this table suffices to show that the geothermic scale increases with the depth in every observation here noted. Former

representations of a uniform rise in temperature proportional to the increase in depth, giving a constant scale which was roughly stated at 30 meters depth per degree centigrade, or 55 feet per degree Fahr., are thus confuted at the outset, not only in regard to any individual locality, but also in comparing widely diverse regions; for while that value of the geothermic scale would be nearly reached at Yakutsk at 400 feet depth, it is not attained till, 1,400 feet at Nausalzwerk, and 2,300 feet in Java. From this observed increase of the geothermic scale in higher latitudes, where the mean annual temperature of the locality is lower, it may be inferred that the earth's crust is probably thicker in polar regions, and thinner near the equator.

Plotting in the form of diagrams the principal data in the table, the author tries how closely the curves so obtained can be fitted by hyperbolic, logarithmic, and parabolic curves; and thereby arrives at presumptive evidence in corroboration or otherwise of certain of the observed data thus employed. From his previous equations for the outward transmission of central heat, he deduces a hyperbola as representing also the inverse penetration of external cold into a solidified sphere, formerly hot and now cooling from its surface inwards. But the idea of the earth's solidity throughout to its very center, already seen to be irreconcileable with the theory of the outward transmission of central heat, is equally incompatible with the observed inward penetration of cold, inasmuch as the geothermic progression deduced from the observations in Java would assign to the earth's solid center a temperature not exceeding the boiling point of water.

Law of Geothermic Progression.—For the complete curve of geothermic progression therefore the author combines these two inverse modes of investigation; and by this means he finds the relation between the depth x below the earth's surface, and the corresponding temperature y, to be exactly represented by the equation

$$y=\frac{TR^2+CRx}{(R-x)^2}-\frac{H(T-t)}{H+x},$$

where R is the earth's radius, and C, H, T, t, are constants for any indi-

TABLE OF OBSERVED SUBTERRANEAN TEMPERATURES, AND CORRESPONDING INCREASE OF GEOTHMERIC SCALE.

Bore hole or well.	Depths below surface.		Temperatures noted.		Geothermic scale.	
	Meters.	Feet.	Centigrade.	Fahr.	Meters per deg. Cent.	Feet per deg. Fahr.
Bore holes at Batavia, and at Grissée, in Java. Latitude 6° S.	0	0	26.0	78.8	12.5	22.7
	70	230	31.6	88.9	15.6	28.4
	140	459	36.1	97.0	18.0	32.8
	165	541	37.5	99.5	20.0	36.4
	416	1,364	48.0	118.4	31.2	56 8
	728	2,388	58.0	136.4		
Artesian bore hole at Grenelle, Paris. Latitude 49° N.	0	0	10.7	51.3	25.9	47.1
	298	977	22.2	72.0	45.3	82.4
	547	1,794	27.7	81.9		
Bore hole at Neusalzwerk, Westphalia.	0	0	10.0	50.0	19.5	35.5
	189	620	19.7	67.5	29.7	54.1
	418	1,371	27.5	81.5	45.7	83.2
	697	2,286	33.6	92 5		
Bore hole at Rüdersdorf, near Berlin. Latitude 52° N.	0	0	9.1	48.4	15.5	28.2
	124	407	17.1	62.8	25.3	46.0
	286	938	23.5	74.3		
Bore hole at Sperenberg, near Berlin Latitude 52° N.	0	0	9.0	48.2	17.4	31.7
	220	722	21.6	70.9	26.0	47.3
	345	1,132	26.4	80.0	33.4	60.8
	659	2,162	35.8	96.4	37 8	68.8
	1,064	3,490	46.5	115.7		
Well at Yakutsk, Siberia. Latitude 62° N.	0	0	−10.3	13.5	7.2	13.0
	15	50	− 8.2	17.2	10.9	19.8
	30	100	− 6.8	19 8	15.2	27.7
	45	150	− 5.8	21.6	19.1	34.8
	60	200	− 5.0	23.0	21.6	39.0
	75	250	− 4.3	24.3	28.8	52.4
	116	382	− 2.9	26.8		

vidual bore hole, t being the observed surface temperature in that particular locality, and T the temperature communicated to the surface at that place from the earth's hot core. The equation represents indeed simply the difference between the hyperbolic curve $y_1 = \frac{TR^2 + CRx}{(R-x)^2}$, already arrived at by the author for the outward transmission of heat through the earth's crust from its hot core, and the true hyperbola $y_2 = \frac{H(T-t)}{H+x}$, representing the inward penetration of cold from the earth's surface; and H is the height above the earth's surface of the temperature asymptote to this hyperbola of cold penetration. The three constants, C, H, T, are determined by assigning any three pairs of observed values to x and y; and the three temperature observations employed for the purpose should be taken as wide apart in depth as possible. The tedious determination of these constants is much simplified, without materially impairing the correctness of the results, by noting that the extreme depth included in the foregoing table does not exceed 3,500 feet; and that as far as 1,760 feet depth at least, or one-third of a mile, the fraction $\frac{x}{R} = \frac{1}{12{,}000}$ may be neglected in comparison with unity. Then the above equation for the law of geothermic progression assumes the simpler form

$$y = T + \frac{C}{R}x - \frac{H(T-t)}{H+x}.$$

The complete curve of geothermic progression presents a point of inflection, at which the geothermic scale will attain its maximum value. Considering by how very large an amount the temperature of the earth's fused or igneous core, even if assumed no higher than 3,000° C. or 5,000° F., exceeds the surface temperature, in comparison with the difference between the surface temperature and the absolute cold of the universe (−276° C. or −465° F.), it follows that the point of inflection in the geothermic curve must occur very much nearer to the earth's external surface than to the interior surface of its crust; and the author calculates that the maximum value of the geothermic scale, occurring at the point of inflection, will be but very slightly greater than its mean value for the entire thickness of the earth's crust. The depth at which the mean value will be attained of the geothermic scale for the whole thickness of the earth's crust in the thinnest portions is probably not more than 3,000 meters (10,000 feet). In Java, where the geothermic scale starts from the surface at about 12 meters per 1° C. or 22 feet per 1° F., its mean value is calculated at 54 meters per 1° C., and its maximum at 57 meters, or 100 feet and 105 feet respectively per 1° F. At Yakutsk, with 7 meters per 1° C. or 13 feet per 1° F. at starting, the mean value would be 155 meters per 1° C. or 280 feet per 1° F.

Other general conclusions arrived at by the author are, that the observed regular increase in the geothermic scale proves the earth to be in process of gradual cooling from a primeval uniformly heated state; but that, as the loss of heat from its surface, though incessant, is infinitely small in comparison with its store of central heat, a large portion of its interior mass must still remain at a very high temperature. Assuming 3,000° C. or 5,000° F. as the temperature of its fused or igneous core, the thickness of the crust in its thinnest or equatorial portion is probably not more than one-fortieth of the earth's radius, and in the thickest or polar portions three or four times as great, or even more. The thickness in any given latitude will also be greater beneath a deep ocean, owing to the mean temperature of the sea being lower than that of the land; thus the most sudden differences of thickness will occur under a latitude where, with a high mean temperature at the surface, the alternations of land and deep sea are the most frequent; and this view is in keeping with the mainly volcanic character of the islands in the equatorial archipelago. Local disturbances, such as volcanic eruptions, earthquakes, and geysers, as well as gradual upheaval or subsidence of tracts of land, cannot be more simply explained than by the reaction which the earth's solidified crust, of considerable thickness, and possessing low conductivity for heat, exerts upon its fused or igneous core.

COMPRESSED AIR UPON TRAMWAYS.

By W. D. SCOTT MONCRIEFF.

From "Nature."

FEW persons unconnected with the practical working of the companies are aware of the great amount of time, labor, and money which have been devoted to the substitution of mechanical for horse power upon tramways both in this country and abroad. The principal incentive to this exertion has been the large margin of saving which has presented itself in the light of a premium to inventors and capitalists. Motives of humanity toward the horses have also had considerable influence, especially with Parliament, and have contributed in no small degree to the legislative sanctions which have been obtained not only by particular companies, but by the tramway interest in general. In no case, however, that the writer is aware of, have the tramway companies themselves made any material contributions towards the solution of the problems involved. When the story of the subject comes to be written it will be found full of arguments in favor of the principle that the monopoly granted to inventors by the patent laws is nothing more than a clumsy method of spurring them to exertion, and of providing a remuneration for success which never covers the aggregate losses of failure by which the whole community have been indirectly benefited.

The fact of the horse-tramway companies having refused to assist inventors with money is fully accounted for and rendered excusable, not only because they have no funds placed at their disposal by their articles of association for such a purpose, but also because the investment would have been far too speculative to have been sanctioned by the shareholders. Where the companies appear to the writer to have been at fault is that while the margin of saving as between a successful invention and horse traction is admitted to be enormous, because the invention could hardly be said to be successful unless the margin was a large one, they have never admitted either individually or collectively that some substantial share of the saving should be the reward of the successful inventor. The writer has no hesitation in saying that if the leading companies had put the issue clearly before the inventive capacity of the engineering profession in the shape of an offer of say 30 per cent. of the actual saving in the shape of royalty to the inventor that the problem would have been solved at least six years ago. The far-stretching results of such a revolution, even within the comparatively confined area of the tramway interest, would be incalculable. Not to speak of the emancipation of the horses, the employment of capital in channels so consistent with the spirit of the age and the genius of the country, as the manufacture of machinery, would have economic results affecting the welfare of whole classes of the community, and the impetus given to the intramural locomotion of our large cities would go far to overcome the pressure of difficulties affecting the housing of the poor, which contribute more to the unrest of the people and the propagation of socialistic ideas than the wealthier classes are aware of. The policy of the tramway companies, however, in appears to have assumed the character of a fixed determination to give nothing in return for the advantages which would accrue to them from the adoption of a successful mechanical substitute for horses. So long as they maintain this attitude the problem is likely to remain unsolved. Licenses of inventors have followed their example, and at least one case is known to the writer in which a gross breach of agreement has debarred the adoption of an invention which is notoriously efficient. Time no doubt will expose the guilty parties, and their names, instead of being honorably associated with the advance and improvement of mechanical science, will be handed down to posterity with the contempt which they deserve.

A description and illustration have already been given in these pages of a system of tramway traction by means of

electricity, and this is no doubt safe in the hands of the distinguished specialists who have taken it up. In the paper which the writer read recently before the Institute of Mechanical Engineers at Manchester, and which has already been reproduced in the engineering journals (see *Engineering*, vol. xxxii., No. 829), a sufficient explanation of his views was given upon the merits of the use of steam locomotives upon tramways compared with compressed air. The objections to steam were based principally upon its failure to comply with the necessary conditions of street traction, in the matter of freedom from smell and dirt, and also on account of the excessive cost incurred by the maintenance of small high-pressure boilers and machinery. No such objections can be urged against the use of compressed air, as compared with electricity, because in both cases there is nothing to give trouble or annoyance from the residual products. In the one case the air escapes in its original purity to the atmosphere from whence it was derived, and in the other a still more subtle transference of force occurs, in which the conversion of one form of energy into another is all that takes place in order to effect the object aimed at. The overhead wire, in the Siemens system, which is the stage at which the invention at present stands, is a disadvantage as compared with a self-moving car in which no such obstruction is necessary to its working. Overlooking this objection to the rival system which may possibly be overcome by the use of accumulation of electric force in the vehicle itself, the point upon which the success of both must ultimately turn is that of their comparative economy. At present there are no figures to hand that can satisfactorily decide the question. In both cases a stationary engine is a necessary adjunct in order to supply a source of energy, and the future of both hinges (1) upon the comparative cost of the plant, and (2) upon the percentage of useful work which can be obtained from the use of compressed air and electricity respectively. These questions can only be answered by the trial of both upon a commercial scale, but it may safely be said in the meantime that there is nothing to lead to the conclusion that compressed air will appear to a disadvantage either as regards the necessary outlay in machinery or in the percentage of useful work to be obtained from it, as compared with electricity.

The conditions which effect the useful effort exerted by a steam engine through the intervening medium of a permanent elastic fluid such as air, employed as the ultimate vehicle of the original force upon a piece of mechanism, are first the loss from friction of the compressing apparatus; second, the loss represented by the difference between the temperature of the air as freshly compressed without radiation, and the temperature of the air as used in the second engine. These may be spoken of as the primary losses of energy. The secondary losses are: first, the friction of the secondary engine; and secondly, the losses arising from its inability to utilize the whole of the force contained in the air as compressed and cooled. Now the theoretical losses arising from these various causes are all easily determined, with the exception of that arising from the defects of the secondary engine, and this, which amounts to more than all the rest put together, not only varies in each separate case, but may be fairly looked upon as being capable of indefinite reduction by discoveries and improvements in the apparatus itself.

With regard to the fixed losses; the one which occurs from the loss of heat, due to compression and subsequent cooling, is one that can be restored under circumstances of peculiar economy, as there is perhaps no condition in the whole range of physics which lends itself so readily to the economical conversion of heat into work as raising the temperature of an elastic fluid under compression and making use of it at a corresponding pressure. It must be remembered, however, that what we are dealing with in practice is not so much the saving of every heat unit of the original supply for the purpose of producing a theoretical result and a beautiful experiment, as bringing the gross expense of the fuel used in the original steam boiler to a point that leaves a sufficient margin as compared with horse traction, and in such a manner as not to interfere with the convenience of passengers. The writer has already in actual

practice brought this gross sum per mile for fuel to ½d., when coal is used costing 10s. a ton, a common-enough price in districts where tramways are in use. Now in attempting to reduce the cost of fuel to a smaller fraction of a penny than ½d. per mile run, it occurred to him that the effort should be made first in the direction in which the greatest loss occurred. This is certainly to be found in the defects of the secondary engine if an ordinary reciprocating steam engine is employed, and an explanation of the writer's work in adapting it to the use of compressed air will be found in the paper already referred to. The result of his experience has gone to show that it is hopeless to obtain an economical result from reciprocating engines as at present arranged for the use of steam, without some special appliances such as he has adopted for making use of the ever-varying rates of expansion necessary in the case of a self-moving car. By reason of the additional apparatus required for re-heating the air resulting in grave inconvenience, and effecting an economy of perhaps not more than one-fifteenth of a penny per mile in fuel, he has not as yet included a heating appliance in the arrangements, and strong arguments would require to be brought to bear upon him before he determined upon doing so. The importance of introducing a heating apparatus would turn more upon what might be gained by adding to the capacity of a self moving air-car with the view of making it capable of overtaking a particular journey for which the cold air was insufficient, than upon a mere question of economy, but even in this case he believes it would be more convenient and economical to add to the quantity and pressure of the air in the receivers than to make use of a separate heating appliance to obtain the same result.

Compressed air as a locomotive power is represented by three different systems, known respectively by the names of their inventors. All of them are more or less protected by patents, and taking the dates of the patent specifications as the standard of priority, the writer's stands first upon the list. The other two are known as Mékarski's and Beaumont's. The writer is the only one of the three who has made public in this country, otherwise than by patent specifications, the scientific work which he has overtaken, and the exact principles upon which his engines have been constructed. Before Col. Beaumont took out a patent at all he had driven in the writer's car and examined it, but as he has departed from his original specification the writer has had no means of comparing the efficiency of the engines, as recently constructed, with his own. On the occasion of his reading the paper at Manchester, already referred to, a letter from Col. Beaumont was read by M. Bergeron, in which it was stated that the engine now running at Stratford used 10 cubic feet of air per mile, at 1,000 lbs. pressure per square inch, or 666 cubic feet at atmospheric pressure. This efficiency is more than 50 per cent. less than the writer's car, without allowing for the loss of power arising from the use of a heating apparatus, and the higher initial pressure of 66 as compared with 26 atmospheres to begin with. If this statement is correct the writer's views with regard to a moderate pressure and avoiding the use of a heating apparatus, except when absolutely necessary, are fully confirmed.

A heating apparatus, and reducing the initial pressure of the air by means of what is known as a reducing valve, are essential elements of the Mékarski system, but the engine would require to be considerably modified before it could comply with the requirements of the Board of Trade in this country.

The experiments which are now being made by the Beaumont Compressed Air Engine Company, at Stratford, with a separate engine, hauling an ordinary passenger car behind it, are likely to bring the question prominently before the notice of tramway companies, and the hopeful remarks made before the last meeting of the British Association, by Sir Frederick Bramwell, with regard to the use of compressed air, must have contributed towards the same result. The experience of the writer who has been longer at work on the subject than either of the representatives of the systems referred to is, however, so much opposed to their proposals, that he does not feel himself to be an altogether unbiased critic of their proceedings. It is sincerely to be hoped, for the sake of

suffering horseflesh, and in order to promote the expansion of intramural locomotion throughout the country, that a fair trial may soon be given to the rival systems, including electricity. This, however, is but a remote contingency if tramway companies continue to adhere to the principle, or rather no principle, that they have to get everything, and the men who add to their dividends nothing, for their pains. The writer's car, which can be seen at work by any one interested, is entirely self-contained, and offers absolutely no obstructions to the convenience of passengers, and it carries forty of them a distance of more than seven miles, with a low and safe pressure of air in the receivers, and without replenishing the supply. The distance it would travel with the pressure used in Col. Beaumont's engine is over twenty miles with one charge of air. The weight complete, including the fittings for passengers, is less than that of any compressed-air tramway engine which the writer knows of, hauling a tramway car behind it.

ALEXANDER LYMAN HOLLEY.

By ROSSITER W. RAYMOND,
Editor of "Engineering and Mining Journal."

In the paralysis that follows the shock of a great personal bereavement, it is not wonderful, though I find it at this moment most lamentable, that I cannot write of the life and character of him who has departed, with the calmness and fullnesss which the subject deserves. If one might weep or cry out in print, feeling at least might find some fit expression, though the mourner would be but a poor substitute for the biographer. But now, alas! I can do justice neither to his virtues nor to my own grief.

It is perhaps fortunate that a part of the work which I cannot to-day find heart or strength to perform, I have done already, under happier auspices. In May, 1879, after the presentation to Mr. Holley at Pittsburg, of a handsome testimonial from the leading Bessemer manufacturers and other friends, I published in these columns, to supplement the report of that event, an account of his career, which I here reproduce. It was carefully prepared as to dates and leading facts; and it has furnished the material for nearly all the notices which have appeared in the newspapers since his death, though in some cases, by careless condensation, that material has been sadly distorted.

Alexander Lyman Holley was born in 1832 at Salisbury, Conn., (where the Institute of Mining Engineers enjoyed, at the Amenia meeting in 1877, the charming hospitality of his parents, Governor and Mrs. Holley). Before his eighteenth year he learned the machinist's trade, and subsequently graduated in 1853, from the scientific course of Brown University, having preferred this training to the classical course at Yale, for which he had been prepared. We cannot help thinking that the classical beginning has had more to do with his success in life than he would probably suspect. To some such influence should be ascribed the general culture and the literary skill which have made his technical knowledge doubly effective on the minds of men.

After graduation, he was employed in a large locomotive works at Providence, and for about a year drove one of the locomotives of the concern on the Stonington Railroad. The following passage from his eloquent address at the Washington meeting of the Institute, on "The Inadequate Union of Engineering Science and Art" (Transactions, iv. 194), shows how powerfully he could feel and express the poetry as well as the practice of that position:

"The thoughtful locomotive-driver is clothed upon, not with the mere machinery of a larger organism, but with all the attributes, except volition, of a power superior to his own. Every faculty is stimulated, and every sense exalted. An unusual sound amid the roaring exhaust and the clattering wheels tells him instantly the place and degree of danger, as would a pain in his own flesh. The consciousness of a certain jarring of the foot-plate, a chattering of a valve-stem, a halt in the exhaust, a peculiar smell of burning, a sudden pounding of the piston, an ominous wheeze of the blast, a hissing of a water-guage—warning him respectively of a broken spring-hanger, a cutting valve, a slipped eccentric, a hot journal, the priming of the boiler, high water, low water, or failing steam—these sensations, as it were, of his outer body, become so intermingled with the sensations of his inner body, that this wheeled and fire-feeding man feels rather than perceives the varying stresses upon his mighty organism."

Either at this time, or during his subsequent connection with locomotive works at Jersey City, occurred a humorous incident which we have heard Mr. Holley relate, and which is perhaps worth repeating. He made a wager with some of his fellows that he could run a locomotive a mile without fire, water, or steam—the locomotive to be taken empty and cold from the shop, and towed by another engine to a point at some distance on the road, where a level stretch of track favored the ex-

periment. Young Holley rode in solitary state on his cold locomotive to the scene of trial, and unsuspected by his escort, so arranged matters that during the trip the motion of the drivers and pistons stored the boiler with compressed air! Of course this gave him, by the time the destined point was reached, an accumulation of power, by means of which he ran out his mile and won his wager.

Before 1855 he had published several technical papers, and had contributed not a little to the columns of Zerah Colburn's *Railway Advocate*. In 1856, he bought the paper, and edited it for about a year, when Colburn resumed his connection with it, Holley retaining half. The hard times of 1857 caused the suspension of the enterprise, and Colburn and Holley went to Europe to study, in the interests of leading American railroad companies, the features of foreign practice. In 1858, their book on *European Railways* was published, Its circulation was large, and its effect was profound. To it may be attributed the rapid improvement in American permanent way and the introduction and perfection of coal-burning locomotives.

Colburn returned to Europe to edit the *Engineer*, and Holley engaged actively in professional writing, chiefly in the editorial columns of the New York *Times*. In 1859, he accompanied Henry J. Raymond to Europe as a *Times* correspondent. In this capacity he made the acquaintance of Brunel and Scott Russell, and thoroughly studied the structure and details of their new marvel the Great Eastern. After a brief interval of editorial work on the *American Railway Review*, he again went to England for the New York *Times* in 1860, to return on the first transatlantic voyage of the Great Eastern. His account of the voyage, and his discussion of the problems of marine engineering and of ocean commerce over the signature "Tubal Cain," attracted much admiration, by their striking combination of picturesque description and technical criticism both thorough and bold. It will be remembered that the New York *Times* editorially prophesied, much to the scorn of several professional papers, that screw steamships would soon drive the side-wheelers, even for passengers, from the North Atlantic. It was Holley who made the prophecy; and we need not say that events fulfilled it. Time vindicated the *Times*.

In 1860 appeared Holley's *Railway Practice*, which immediately took the place of a standard authority. He must have been collecting the materials for this work, during the two preceding years, when he appeared to be wholly occupied with his work as a journalist. His astonishing activity, indeed, eludes our attempts to trace it in detail. We find him superintending experiments in fuel, permanent way, etc., for railway companies, acting as expert in patent cases, and even preparing about a thousand engineering definitions and several hundred illustrations for *Webster's Dictionary* (edition of 1864).

An acquaintance formed through some one of these channels with the late Edwin A. Stevens, at the beginning of the war, led to a temporary connection with the "Stevens Battery," and to the sending of Mr. Holley to England in 1862 to investigate ordnance and armor. The ultimate result of these studies was the book on that subject, published in 1865, which was of itself enough to establish the position of its author in the engineering world. It met with immediate appreciation at home and abroad, was translated and republished in France; and although it is now, of course, behind the times, it remains the standard authority for the state of that branch of the military art at the time of its appearance.

The connection of Mr. Holley with the development of the Bessemer process in the United States is the most important part of his career thus far. It was he who negotiated the purchase of the Bessemer American patents in 1864, built the experimental works at Troy and started them in 1865, built the Harrisburg works in 1867 and superintended them until 1869, rebuilt the Troy works, planned the works at North Chicago and Joliet, the superb Edgar Thomson works at Pittburg, and the Vulcan works at St. Louis. Moreover, it was to his improvements in the mechanical arrangement and details of the Bessemer plant more than to the contributions of any other one man that the astonishing development of the process was due. Mr. Robert W. Hunt, himself one of the earliest and most eminent of our Bessemer engineers, says in his paper on the "History of the Bessemer Manufacture in America" (Trans. Am. Ins. of M. E., v., 201):

"After building the first experimental plant at Troy, Mr. Holley seems to have at once broken loose from the restraints of his foreign experience, and to have been impressed with the capabilities of the new process. The result is, that mainly through his inventions and modifications of the plant we in America are to-day enabled to stand at the head of the world in respect of amount of product."

The example of America has not been without influence abroad. In 1864, the maximum daily product of a pair of five-ton converters in England was 30 tons of steel. We believe it is now perhaps 150 tons per 24 hours there; while in the United States the present average production is 300 tons per 24 hours, and the Edgar Thomson Works have actually surpassed the enormous figure of 9000 tons of steel ingots in one month* (the converters not running on Sundays). We quote again from Mr. Hunt's admirable paper the following summary of Mr. Holley's contributions to this unparalleled record of progress:

"The result of his thought gave us the present accepted type of American Bessemer plant. He did away with the English deep pit, and raised the vessels so as to get working space under them on the ground floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel

*It has since exceeded 14,000 tons.

as related to the pit and melting-house; he modified the ladle-crane, and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces, and last, but by no means least, introduced the intermediate or accumulating ladle, which is placed on scales, and thus insures accuracy of operation by rendering possible the weighing of each charge of melted iron, before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant, he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel-bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments, the result was the Holley vessel-bottom, which, either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production."

To say nothing of his incidental literary work in marine engineering and other departments which stamped him as a critic of the first order, any one of these achievements would have entitled him to an honorable professional position. Their union in one man, scarcely arrived at his prime, is almost without parallel.

Mr. Holley was the first editor of VAN NOSTRAND'S ECLECTIC ENGINEERING MAGAZINE; but even he could not long carry that burden in addition to his multifarious professional labors. Since 1870, he has been actively engaged as consulting engineer to numerous Bessemer and other steel works, making frequent journeys to Europe, and issuing to his clients periodical reports of great value. His connection with the open-hearth steel manufacture, and particularly with the introduction of the Pernot furnace and other improvements, which seem likely to effect great progress in that department, is a matter of current history.

As President of the American Institute of Mining engineers in 1875–6, and first Vice-President of the Society of Civil Engineers in 1876, he made his energy and genius felt in both societies, and contributed no little to the growth of that *entente cordiale* which characterizes their relations. The pages of their transactions, as well as those of various cyclopedias, bear witness to his industry, professional enthusiasm, and literary power. His work as a member and advocate of the U. S. Testing Board will be remembered as specially effective.

We are writing, not eulogy, but history. Yet even history may be pardoned, in such a case, for infusing into the words of justice some of the warmth of affection. At a brilliant banquet of the Institute in Pittsburg, the other day, one of the speakers, alluding to the testimonial presented to Mr. Holley the evening before, uttered the feeling of every member of that body, in declaring that the sentiments which had inspired the gift were shared also by those who had not enjoyed the privilege of uniting in such an expression of them. From the verses with which that speech concluded, we quote the final stanzas. Whatever their demerits as poetry, they were offered by the speaker and received by the audience with a feeling that left no doubt of their sincerity and their fitness.

"The Macedonian wept with rage
For other worlds to overrun;
The hero of a nobler age
Has found and claimed them, one by one.

"Realm after realm of fruitful thought
Has hailed our ALEXANER king;
But crowns of conquest all are naught
To those our loyal hearts would bring!

"For weakness at the victor's feet,
Or reason, may reluctant bend;
But love's surrender is complete,
The utter gift of friend to friend.

"O, brother! known in many lands,
And master called in many arts,
Behold, we stretch to you our hands
With nothing in them, save our hearts!"

Who of those who were present will ever forget the presentation to which allusion is made in the above article? Already Holley's health was in such a state as to excite the anxiety of his friends; and there was a terribly pathetic significance in the exquisitely beautiful close of his *extempore* speech:

"Among us all who are working hard in our noble profession, and are keeping the fires of metallurgy aglow, such occasions as this should also kindle a flame of good-fellowship and affection which will burn to the end.

"Burn to the end! Perhaps some of us should think of that, who are burning the candle at both ends. Ah! well, may it so happen to us that when at last this vital spark is oxidized, when this combustible has put on incombustion, when this living fire flutters thin and pale at the lips, some kindly hand may turn us down, not underblown—by all means not overblown—some loving hand may turn us down, and that we may perhaps be cast in a better mould."

A somewhat (but not sufficiently) greater moderation in the intensity of his labors did produce, after this period, a partial restoration of health. But health, with Holley, meant only more power to work. He was like a prodigal who saved merely that he might spend. And so, after a year, it came to pass that he lay at the point of death in London, and a thousand hearts beat with alternate hope and despair, keeping time with the pulses of the ocean cable that brought the tidings of his fluctuating condition. Finally, in August, 1881, the joyful news of his almost miraculous recovery reached this city, in time to be

telegraphed to the Lake Superior meeting of the Institute of Mining Engineers; and in the following February he appeared among us, with all his old winning grace and humor, though not with his old vigor. That was another memorable scene, at the Philadelphia banquet in February last, when the large and brilliant assembly welcomed again their well-beloved, and hung upon his words, as with undiminished power he moved them to alternate laughter and tears. We remember, as an instance of consummate art (if it was not rather nature-excelling art), the manner in which, after graphic allusion to his suffering and critical condition abroad, and to the cordial cable telegram sent him from the Lake Superior meeting of his brethren, he paused, and then broke out with thrilling Saxon simplicity: "Oh! how that made me feel!"

A year has passed—for him another year of zeal and activity, in spite of recurring weakness; a year in which, though he struck into no new line of inquiry, he performed some of the best professional work of his life, and perfected what may hereafter be recognized as his greatest invention. We refer to the movable converter shell—an improvement in the Bessemer plant which bids fair to rank with the movable coverter-bottom, and to carry to the utmost limit the productive capacity of the Bessemer process. It was while he lay desperately ill in London that he conceived the idea of this invention, and told a friend who called upon him that he had been "thinking, to pass away the time, and had thought of something which would enable him to die with credit!" This humorous remark expressed a constant characteristic of his mind. His occupation as a consulting engineer, of detecting the weak points in methods and means, and suggesting the best remedies, of hunting up "good things" and recommending them to his clients, was in exact consonance with his disposition. It enabled him to be constantly helping somebody.

We can not now lament that this year of fruitful activity on his part was not rather a year of rest. His impulse was wiser than the prudence of those who would have bid him forbear. For the autopsy performed since his death has shown that the malady under which he had already suffered, and which had puzzled the doctors, was incurable in its nature, and, we may fairly say, not directly traceable to over-work—a tumor, obstructing the gall-duct, and producing many apparent symptoms of liver disease. He was attacked, during a professional journey in Belgium, early in the autumn, with chills and fever, which he ascribed to the malaria of the Low Countries. In spite of the obstinate persistence of this trouble, he managed, before finally breaking down, to finish the work he had laid out in England and Scotland. Then he laid aside for the last time the pen and pencil that had done such splendid service—and the rest of the story is but a monotonous record of patient endurance, heroic courage and cheerfulness, unselfish thought for others, and a calm and absolutely unaffectedly fearless reception of the death message. The immediate cause of his death was *peritonitis*, which suddenly changed what seemed, even to critical eyes, to be but a tedious recovery, into a swift decline. At my last interview with him, only two days before his case became hopeless, and five days before his death, he said (and I thought he was right) that it would be "a long pull," but he should "pull through."

What a Sabbath followed! The quiet chamber where he lay, brave and cheerful, watching and measuring the strength that was ebbing away, as he might have watched and measured the current of a motive power; the storm beaten ship that steamed up the harbor, bearing those he loved best; the race with death; the arrival of wife and daughters, just too late (God comfort them!)—what insupportable wringing of all hearts, except his, who recognized with calm impartiality when the machinery of life was about to stop, and whose only anxiety was for those who were sailing unawares toward the shadow of death! "Make it as easy for them as you can," he had earnestly said to a faithful friend.

And now the "living fire," fluttering "thin and pale at the lips," has gone out altogether. The heat is over. The bright, true steel has been "cast in a better mould;" and we, who so lately looked upon the brilliant display, now stand in darkness. But the figure fails

here. Neither to him nor to us is this the end. For us remains a rich inheritance of knowledge, bequeathed by him, and still more precious treasure of shining example and of tender memory; for him, an earthly fame that might satisfy the highest ambition, and a new life unspeakable, incomprehensible, of powers and opportunities here unknown.

Nay, for me, at least, there still remains a sense of the abiding presence of my dear friend. That flashing spirit, that gentle heart, that hand, so cunning in skill, so cordial in friendship, shall not pass out of my life. Though all the bells of the earth ring funeral peals, I will not say farewell!

REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.—The annual meeting took place on the 18th of January. The first business of the meeting was the election of officers for the ensuing year. The election resulted as follows: President, Ashbel Welch, of Lambertville, N. J.; vice-presidents, James B. Eads, of St. Louis, and William H. Paine, of Brooklyn; secretary and librarian, John Bogart of New York; treasurer, J. J. R. Croes, of New York; directors, Thomas C. Kiefer, of Ottawa, Canada, Colonel Thomas L. Casey, United States Army, Joseph P. Davis, New York, George W. Dresser, New York. Mr. Welch, on taking his seat as president, read an address thanking the members for his election. He said that the society represented every race and clime, and that in the last year proposals for membership had been received from Mexico, Chili, Columbia, England and India. In conclusion he urged the members of the society to "cultivate a wholesome integrity such as preserves the purity of the bench and of the army."

The committee to award the Norman medal reported progress and was continued. The secretary then read the report of the Board of Directors. This report showed the membership of the society to be 605, with 52 Fellows; 62 new members were added in the last year, and 16 members were lost by death, resignation and transfer. The committee on a uniform test for cements, made a report. Sanford Fleming, of Ottawa, chairman of the committee on a uniform system of time, presented the report of his committee, which recommended a general convention of the Government departments and the societies of this country, Canada and Mexico, interested in the subject. The scheme proposed is the establishment of a new system of reckoning time so that it shall be uniform at all points in this country. It is proposed to take a certain meridian, and when it is 12 o'clock there have it called 12 o'clock all over the country. If found necessary or advisable the division of the day into twelve hours is to be done away with and a new division substituted. General Theodore G. Ellis, of Hartford, said that a clock was now being constructed by the Waltham Company which the Signal Service is to set up in Washington, and the clocks of the different stations are to be set to correspond with it, thus avoiding the discrepancies in the computations of time which now occur.

At the afternoon session a committee of directors reported on the subject of tests of American iron, steel and other metals. At the previous meeting a committee had been appointed on this subject with instructions to report to the committee of direction, and its report was transmitted by the board to the meeting. The report recommended that a board be appointed by the Government to superintend the testing of iron, steel and other metals used in construction; that bridges of iron and steel should be included in the tests, and that they should be conducted by a civil board or one composed of officers of the Army and Navy. The report was finally accepted, and a resolution passed directing the committee of direction to take such measures without expense, as it thought expedient to get Congress to establish the Board of Tests and make an appropriation therefor.

A resolution was passed thanking T. F. Rowland for his generous contribution to the building fund of the society, and the Board of Directors was instructed to establish an annual medal of the value of $50, to be known as the Rowland medal, to be offered for excellence in essays read before the society.

ENGINEERS' CLUB OF PHILADELPHIA—Regular meeting of January 21st, 1882.

A paper by Prof. W. S. Chaplin, on the "Relative Tensile Strengths of Long and Short Bars," was presented, on his behalf, by Prof. L. M. Haupt. The object of this paper is to prove that long bars are, on the average, weaker to resist tensile stress than short bars of the same material and cross section, and to show how the reduction in strength may be found when the proper experiments have been made on the short bars.

The Secretary presented a correspondence, in the year 1839, upon the subject of Street Paving, between the Chairman of the Committeee on Public Highways, of the City of Philadelphia and Mr. Thomas U. Walter, Honorary Member of the Club, who was then in Europe, and was requested to furnish information as to the paving of European cities. His letter treats of the ordinary cobble-stone, wooden, granite-block, cobble-stone with flagstone tramways, McAdamized and natural and artificial asphaltum roadways, and is remarkable as exhibiting how much was known upon this subject over forty years ago and how little we have profited by it in Philadelphia.

Mr. D. H. Shedaker submitted an extract, giving account of an exhibition of electric lighting in Trafalgar Square, London, in 1848. The results were so satisfactory that the writer considered that "after a short time we should not be surprised to hear of the total extinction of half the gas companies in the kingdom."

Mr. Charles A. Ashburner explained some difficulties, which have been encountered in the anthracite coal mines of Schuylkill County where the coal beds have been "pinched out" and lost, but which have afterwards been found by driving tunnels at right angles to the strike of the beds and away from the center of the basin. This irregularity of structure seems to have been produced by a folding of the strata at right angles to the strike, by a force exerted in the direction of the basin.

AMERICAN SOCIETY OF CIVIL ENGINEERS, February 15, 1882. The Society met at 8 P. M., President Welch in the chair. A paper by Mr. R. E. McMath of St. Louis, member of the Society; subject, "The Mean Velocity of Streams Flowing in Natural Channels," was read by the Secretary in the absence of the author. With this paper was presented a set of diagrams of curves, deduced from the experiments of J. B. Francis, member A. S. C. E. at Lowell, from the observations of Gen. Theo. G. Ellis, member A. S. C. E., upon the flow of the Connecticut river, from the records of the flow of the Mississippi, made by Gens. Humphreys and Abbott, and also from various other observations of the flow of the Mississippi at Columbus, Ky.; at Vicksburg, Miss.; at Carrolltown, La., and at the passes at the mouth of the Mississippi.

The author of the paper then presented for consideration and discussion the suggestion that to determine a reliable rule for the flow of streams in natural channels, the considerations affecting an artificial channel should be kept entirely distinct; that the definite law of discharge over a weir is usefully applicable at any transverse section above and within the influence of a weir, dam or shoal; that the relation between mean and maximum velocity cannot be used in streams of irregular section; that head is pressure but not in all cases full of surface; that in natural streams the bars or shoals are substituted for the weir or dam; that the level of no discharge is determined by the horizontal plane through the crest of a weir, dam or natural bar; that two new hydraulic terms may be used, viz.: Permanent Area, or that part of transverse section below the plane of no discharge, and Ruling Depth or the depth of the plane below the surface. Formulæ are then suggested in application of these considerations. The paper was discussed by Messrs. T. C. Clarke, Ashbel Welch, F. Collingwood, Joseph P. Davis and Charles E. Emery.

ENGINEERING NOTES.

SUBMARINE TELEGRAPHY.—Attention has been prominently drawn to the danger that submarine cables in certain places are subject to, and to some of the delays to which the vessels engaged in the laying and the repair of submarine cables are effected. It appears from a list that has been compiled that there are not fewer than twenty vessels, mostly the property of British companies, engaged in the work of cable laying and repairing. Their tonnage varies from 369 tons to 4,935 tons, the total being 45,629 tons gross. This fact in itself shows the extent of the operations that must be carried on, and the greater importance and the value of the work that the cables so laid are effecting from year to year in the world. It has been suggested that it would minimize the danger to cables, that have of late been prominently brought before the public, if laws were passed to secure rights to the "first comers" on cable "ground," and that the vessels engaged in relaying or repairing should be free from certain Custom House formalities that now press upon them, and causing delay to the vessels, impede seriously the telegraphic communication and the work and commerce of the whole of the world. A case is reported where it has been necessary to land telegraphic instruments for testing, value about £120, and in addition to formalities that caused delay, dues were charged on these to the amount of £118. It is evident then that when the importance of the work of these repairing vessels is borne in mind, that they should have special privileges, for though their's is a commercial mission nominally, it is in reality one that is much more an international one—one that is for the benefit of the whole of the subjects of the nations to be connected together "under the green translucent wave." The vessels of telegraphic companies are practically little more than Queen's messengers—they are the emissaries that keep in order the means of communication between all nations, and they sought to pass unquestioned—their flags being flags of truce. It is to be hoped that in some way there may be a speedy amelioration of the laws that press on the cable vessels, and it would not be too much to express the hope that the representatives of all nations should be appealed to to facilitate this needful work. Up to the present time the owners of the cables have not received too great a return for the capital they have put into the cables, and that capital is invested in an article peculiarly subject to assaults, and yet one that is increasingly becoming the mode of communication between nations severed by the sea, but connected by the cable. It is, therefore, in the highest interest of the nations and the peoples that there should be every facility for the repairing of broken cables, and that the needful works should be gone on with without the stoppage by red tapeism. We have yet only partly reaped the benefits of the submarine cables, for as the system becomes more and more extended, so the efficiency of the whole is increased, and the value of the communication enlarged. It is possible that the cost of telegraphy under the sea may be much further cheapened, but one of the essentials to that further reduction is the facility that is now claimed, so that each cable may perform as much work as possible, and that the revenue of the companies may be increased by the cessation as much as possible of stoppages. There is a further question that may some day come up, whether the Governments of the world ought not to possess international cables of their own, by purchase; but that question can scarcely be said to be as yet "within the range of practical politics," whilst that we

have alluded to is not only so, but is one that presses for early solution.

EXCAVATORS AND DREDGERS IN PANAMA.—Contradictory accounts have been published from time to time of the machinery to be employed for the excavations in the Panama Canal works. The following description of them may be taken as an official one, having been published by the company itself. The excavator, designed by M. Couvreux, is, in fact a dredging machine on dry land, with the necessary modifications to suit the different nature of its work. The excavator, however, cannot stand over its work like a floating dredger, and the endless chain with buckets is therefore placed at one side of it, and nearly horizontal, although some inclination is given to the chain according to the slope of the ground and nature of the soil. The buckets are then driven along the slope of the cutting, scooping out the earth or cutting it away like a succession of planes, and throwing it out on the other side of their round. The excavator can be placed either on the level from which the excavation is to be made, or—in case of a mass of earth to be removed—on the level down to which the soil is to be brought. In every case it stands by the side of the place of work, upon rails of the normal gauge, and moves along continuously while in action. After it has reached the end of the rails they have to be shifted, either to bring it again alongside of the remaining mass to be leveled, or to remove it further from the trench. The great weight of the chain of buckets, with all its apparatus, coming entirely upon one side, and the tremendous strain of the work, so unequally distributed, made the question of securing the balance of the machine a very difficult one. This has been effected by various expedients, of which the principal has been the use of a third wheel on each of the four axles, working on a third rail 20 inches within the outer rail on the side of the chain. The excavator is furnished with two engines; one of 20 horse power drives the chain, the other, of only 4 horse power, moves the machine on the rails. The appearance of the whole is like a very tall locomotive, and the total weight is somewhat over 44 tons. The buckets contain about 6 cubic feet each, and their number varies according to circumstances. They can be driven to the depth of 16 feet. The excavator works at the rate of 80 turns per minute, and on an average (allowing for loss of time) excavates and loads on trucks 84,600 cubic feet of earth per day, thus doing the work of 600 laborers. It only requires the services of a driver, stoker, and two workmen for various purposes, besides the men who remove the rails, which only takes up a portion of their time. The dredging machines employed in this work are of great size and power; they are 110 feet long by 21 feet broad, and weigh when empty about 98¼ tons. The buckets contain about 10 cubic feet each; they can be driven nealy 30 feet deep, and lift their contents to such a height that they can be shot to a distance of 133 feet. The average of work done is nearly as great as that of the excavator.

PROPOSED TUNNEL UNDER THE THAMES.—Some of the local authorities in the east end of London are much exercised at a rumor that the Metropolitan Board of Works have a project under consideration for a tunnel from the Whitechapel road to the south side of the Thames, this being, in their opinion, the best method of satisfying the great need of communication. It would probably be more correct to say that the tunnel is proposed in order to avoid the opposition of the city authorities, who, apparently, will consent to nothing—however much for the good of the metropolis—which may touch the vested interests of Billingsgate and Thames street. At any rate in the East of London, beyond the city, the need is for the bridge, and not for a tunnel, and this view is to find expression at the next meeting of the Whitechapel District Board of Works on Monday, the 19th inst., when Mr. William Smither, the well-known carrier and local representative, is to move: "That in the opinion of this board the proposed means of communication between the north and south side of the Thames below London Bridge should be a low-level bridge." If London had a representative government like every other town and city in the empire, a resolution such as this would have had effect long ago.

SUBMARINE TUNNELS.—Since the works in connection with the Channel Tunnel experiments were commenced at the new heading at Shakespeare's Cliff, the operations have been so successful that the first quarter of a mile is now completed. What looks especially encouraging is that the engineers are able to gradually increase the rate of boring, which has attained the excellent average of thirty-six feet per day; and in addition to this the soil is now quite dry, there being a total absence of springs, the presence of which proved a source of much delay in the Abbot's Cliff heading. There are now about eighty men engaged on the works. They are employed in two night and day shifts, but it is proposed shortly to have an extra shift, making eight hours each in order to expedite the work. No boring is done on Sunday, the men being chiefly employed on that day in lengthening the double line of metals in which the trollies carrying the debris travel. The boring has now advanced several yards under the sea in the direction of the Admiralty Pier at Dover. With regard to the Mersey Tunnel, we are informed that the second shafts on the Liverpool and Birkenhead sides, from which the main tunnel has to be driven, have been completed on each side for some time, and the first section of the tunnel is now being excavated on each side, and will be finished by 1st of January. The whole length of the heading on the Liverpool side has been enlarged previous to bricking, and that at Birkenhead is now undergoing the same process, while the Liverpool heading is being driven forward at the usual rate of eleven to twelve yards per week. About a quarter of the whole length of the heading from shaft to shaft has now been driven without any change in the character of the solid red sandstone rock through which it passes. Both the tunnel and

the heading will be bricked throughout with several courses of brick. New Ferry bricks have been selected for the outer rings, and Staffordshire blue bricks for the inner. The whole will thus be of the best quality.

THE DESTRUCTION OF CALF ROCK LIGHT-HOUSE.—It is fortunately seldom that any serious disaster in connection with the Light-house Service of the United Kingdom has to be recorded, which fact is a silent testimony to the efficiency and permanence of the general arrangements for the marking of our coasts. It is therefore not without a feeling of pain that we have to refer to the recent accident at the lighthouse on the Calf Rock, near Bearhaven, on the southwest coast of Ireland. This light-house was completed in 1866; the tower was of cast iron, lined with brick, 75 feet high, and 21 feet diameter at the base. In January, 1869, a very severe storm took place, during which a portion of the lantern gallery was carried away. Upon this warning as to the exceptionally heavy seas which break on the rock, it was thought desirable, after professional inspection, to strengthen the tower for half its height with an external casing of cast iron, the space between the old and new casings to be filled in with concrete, thereby increasing the diameter to 30 feet at the base, and to reduce the overhanging lip of the gallery so as to offer less obstruction to the waves which might strike the tower. This work was duly carried out, and some small houses were erected on the rock for the protection and convenience of the keepers. Since that period, 1870, nothing alarming has occurred, although it is reported that the sea frequently broke with very great fury upon the rock, the waves at times running up and striking the upper part of the tower with tremendous force. Both this rock and the Fastnet to the south are exposed to the full strength of a southwest gale, there being nothing whatever to break the force of the wind itself rushing across the vast expanse of the Atlantic, nor of the momentum of the waves established by the wind and which "come home" upon these rocks with indescribable violence. The catastrophe now to be recorded is that during a storm on the morning of the 27th November, the whole of the upper part of the tower above the new casing was carried away, the keepers having to run for their lives. Fortunately no life was lost, but as the men could not get off the rock, they were compelled to wait there during a long continuance of bad weather, it being impossible for a boat to get near the rock, and provisions having to be conveyed to them by various expedients. The men managed to obtain some shelter in the small houses already mentioned, but were in a condition of great peril. A change of wind and consequent quieting of the sea at length enabled the men to be taken off, after eleven days' imprisonment, during which they endured much exposure and hardship. With praiseworthy alacrity the Commissioners of Irish Lights have arranged for the exhibition of a light, similar in character to that extinguished, from Dursey Island, and not too soon can so valuable a light be replaced, for no one knows what further disasters may result from its absence. As regards the cause of the giving away of the tower in connection with its design and construction, no opinion can at present be formed, but no doubt the matter will be fully investigated in order that the defect, if any, may be brought to light, and a recurrence of such a catastrophe prevented.—*Nautical Magazine.*

ACCORDING to news by recent mail, the new harbor works at Madras had been seriously damaged, and the cranes at the ends of the northern and southern piers were swept away. The top row of blocks, for about 2,500 feet from the end of each pier, was carried away, and the extremities of the piers have settled down about 2 feet. The steam hopper barges Salisbury and Hobart which were engaged in laying down moorings in the harbor, foundered. Their European captain and about fourteen natives were drowned.

THE directors of the Midland Railway Company are considering a scheme for lighting the entire length of the Erewash Valley stations, junctions, branches, and sidings by electricity It is proposed to light as far as Alfreton by one engine, fixed at Chesterfield, and as far as Pye Bridge by another fixed at Nottingham, the stations being at comparatively short distances apart.

RAILWAY NOTES.

ONE thousand miles of railway are now open for traffic in New South Wales, of which 147 were opened during the current year. Four extensions, aggregating 225 miles, would be laid down next year. The increase of population in the colony since the passing of the Land Act in 1860 was 50 per cent., being greater than in the United States, where the increase had never been more than at the rate of 37 per cent in ten years.

IN a country having a well-developed railway system the number of persons occupied with railway work is such as would form a large army. Thus, according to the *Deutsche Industrie Zeitung*, the number of officials and workmen on the German lines in the end of 1879 was 272,831, while the corresponding number for France the previous year was 182,983. For every 100,000 of the population, 611 in Germany and 493 in France were engaged on railways. The greater number in the former case is explained by the fact that, in relation to surface and population, Germany has a larger network of railways than France. For every 100 kilometers of line the *personnel* is in Germany about 834; in France 827; therefore nearly the same. Dividing the *personnel* into four groups, it appears, first, that the number of persons occupied with "general management" is in Germany about three times what it is in France per 100 kilometers of line, this being mainly due to the greater division of the railway system in Germany, where there are seventy-four railway lines with separate management, as against twenty-one in France. Next, a relatively less number of

persons is engaged permanently in Germany than in France in the line service—second group—and in traffic and commercial service—third—whereas in train and workshop service—fourth—more persons are engaged in Germany. The traffic on the German lines is not, however, busier than on the French; but for the conveyance of the same number of persons, or the same quantity of goods, the same distance, a larger *personnel*—in this fourth group—is employed in Germany. The French statistics show, *inter alia*, that 68,865 persons who had been in the army, were engaged on French railways at the date specified; also, 13,554 women. The former are pretty regularly distributed among all the four groups, and the latter are most largely engaged in line service.

THE WESTINGHOUSE BRAKE.—A limited company has been formed in England and has taken over all the property, rights, and interests of the Westinghouse Continuous Brake Company, which was an American organization. The directors of the new company are Mr. George Westinghouse, chairman; Sir Henry Tyler, vice-chairman; Sir Thomas Douglas Forsyth, K. C. S. I., and Capt. Francis Pavey. The Westinghouse automatic brake has, we are glad to say, made progress. It is now in use on fourteen railways in the United Kingdom, being fitted to 1,087 engines, and 7,719 carriages. In France it is in use on eight railways, and is now, or will be in a very short time, fitted to 1,416 engines, and 7,193 carriages. It is also in use in Austria, Germany, Russia, Holland, Italy, Sweden, India, New South Wales, South Australia, and Queensland. In the United States it was up to September the 30th, 1881, fitted to 3,435 engines and 12,270 cars. The grand total for the world is—engines, 6,599; carriages, 29,562. In sixteen months, that is to say, since July, 1880, there have been fitted 3,322 engines, and 16,060 carriages. With the non-automatic brake, there are 2,579 engines, and 11,389 vehicles fitted in the United States, principally to goods trains. Including both types, there are now fitted 9,236 engines, and 41,350 vehicles. A brake which is in such extended use must be good. The experience acquired with it is enormous, and yet we find English railway companies halting between two opinions, and asserting that they cannot find a satisfactory brake. Under the circumstances this sounds like nonsense, and it is quite certain it will be impossible for any railway company to obtain by its unaided efforts during a few months, a twentieth part of the experience already gained by the Westinghouse Brake Company. Facts constitute very stubborn arguments, and the way in which the Westinghouse brake has made its way in spite of a great deal of opposition, is a fact constituting a most powerful argument in its favor.

IRON AND STEEL NOTES.

THE DEPHOSPHORIZATION PROCESS IN GERMANY.—At the last meeting of the Iron and Steel Institute of Germany held at Düsseldorf, Director Brauns, of the Dortmund Union Steel Works, read a paper on "The Economical Aspects of the Thomas-Gilchrist Process in Germany." The author stated that the process had been worked regularly at the Union works since May last, and that tests were made on a sample from every charge. The experience gained in this way confirmed that obtained by the Rhenish, Hörde, and other works, that there was no difficulty in obtaining uniformly good work as regularly as with ordinary Bessemer steel. They had, moreover, demonstrated that the Thomas steel presented special advantages for the manufacture of railway sleepers, plates, soft steel for wire, &c., even where local circumstances were such as to enable hematite steel to be made as cheaply as dephosphorized steel. The result was that this dephosphorized ingot iron would for very many purposes take the place of puddled iron, and that such of the iron that was now imported into Germany for ship plates and other uses would be replaced by the cheaper and better dephosphorized steel manufactured in Germany. The difficulty of obtaining suitable iron to treat by the basic process has been greatly exaggerated. Experience showed that not only by reason of its being possible to use phosphoric ores, but in every other respect, the manufacture of a suitable basic pig was far easier and cheaper than the manufacture of ordinary Bessemer iron. It was found that the output of a blast furnace on Thomas-Gilchrist pig iron would exceed by from 25 to 30 per cent. the production of a blast furnace on Bessemer pig; while the campaign of the furnace working on the latter would be much shorter. White iron is generally preferred to grey iron, and the phosphorus may with advantage be kept between 1¼ and 1½ per cent. The ore districts of Germany that would most benefit by the Thomas-Gilchrist process are Lorraine, Luxemburg, the brown ore region of Bonn, and the black band region of Dortmund; the Ilsede and Upper Silesian and Bavarian works would also be largely benefited. In the discussion that followed, Director Grass stated that his works found the extra costs on the Thomas-Gilchrist process to be 7s. a ton. This would make the Thomas Bessemer steel about 13s. a ton cheaper than hematite Bessemer steel in Germany, where phosphoric iron is at least 20s. a ton cheaper than Bessemer iron.

M. FORQUIGNON, who has published an extensive series of researches upon malleable iron and the reheating of steel, attaches special importance to the following conclusions: (1) Malleable iron always contains amorphous graphite; (2) a casting may lose carbon and yet remain brittle if the original quantity of graphite is not increased; (3) a casting may become malleable without losing any sensible portion of its carbon; (4) if silicium is added to manganesian castings they are improved by reheating; (5) hydrogen and nitrogen may unite with the carbon of a casting so as to make it malleable without the production of graphite; (6) the breaking load is always more than doubled, sometimes more than quadrupled, by annealing—it increases

with the duration of the heating, very rapidly at first and then very slowly; (7) ductility generally increases with the resistance to breaking, but after a certain limit it has a slight tendency to diminish.

ORDNANCE AND NAVAL.

A NEW MACHINE GUN.—The Ordnance Committee recently witnessed at Woolwich the trial of a new machine gun, for which a merit is claimed, far surpassing that of any of its many predecessors. From all of these it differs materially, both in appearance and principle; but, in having ten parallel barrels on a line, it bears a somewhat close resemblance to the well-known French "infernal machine." It is fed by a frame filled with cartridges, 150 in number, and ten in a row. This is dropped into a groove at the breech, and worked to and fro by a lever, each movement forward discharging one row of ten shots, and each movement backward withdrawing the empty cases. By a simple mechanism, adjusted before commencing action, and alterable at will, the barrels can be elevated and traversed right and left as it is being fired, and in point of rapidity it has never been excelled, the ten barrels exploding almost simultaneously, and reloading again as quickly as the hand can move. The sample gun under experiment was, however, unfortunately weak in springs provided for firing the percussion caps, and there were consequently a great many misfires.

THE following are the dimensions of some of the large modern ships:—The City of Rome is 546 ft. in length; the Great Eastern, 676; the Great Eastern in breadth is 82 ft. 8 in.; depth, 60 ft, with a registered tonnage, excluding engine space, of 13,343. She has stowage for cargo to the extent of 6000 tons, and the capacity in her coal bunkers is 10,000. When loaded she draws 30 ft. of water. The City of Rome is 52 ft. 6 in. broad, and 34-38 ft. deep, with a gross tonnage of 8415. While she is thus 16 ft. longer than the Servia and 6 in. more beam, the Cunarder is actually 6 ft. 9 in. deeper, and is said to be able to carry a few tons more cargo. The Cunard Liner Gallia is 450 ft. long and 46 ft. broad, with a gross tonnage of 5000; the Arizona, 466 ft. long and 46 ft. broad, with a gross tonnage of 5500; the Orient, 460 ft. long and 46 ft. 6 in. broad; the Parisian, 450 ft. long; the Anchor Liner, Furnessia, is 445 ft.; State of Nebraska, 395; Notting Hill, 420; Alaska, 525; Spartan, 370; Drummond Castle, 375; City of Calcutta, 400; Kansas—building—435; Austral—building—400; the Clyde, 385; and several of the White Star Liners about 400 ft. long. One of the Cunard steamers, named the Aurania, now under construction in the yard of Messrs. James and George Thomson, is to be of somewhat unusual dimensions, some 485 ft. long and 57 ft. broad, with a tonnage of 7500; and another, the Pavonia, will carry 5500 tons.

IN the course of November 22 vessels, with an aggregate tonnage of 31,170, have been launched from the Clyde ship-building yards as compared with 14 vessels of 26,300 tons in November, 1880. The work of the eleven months consists of 215 vessels of 290,039 tons, against 206 vessels of 213,130 tons in the same period of last year. A large number of new contracts have been placed during the month.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

JOURNAL OF THE MILITARY SERVICE INSTITUTION OF THE UNITED STATES. Vol. 2, No. 8.

MONTHLY WEATHER REVIEW FOR DECEMBER. WASHINGTON: Government Printing Office.

FROM the institution of Civil Engineers we have received through the kindness of Mr. James Forrest, Secretary:

Steel for Tires and Axles. By Benjamin Baker, M.I.C.E.

Experiments with Portland Cement. By Henry Faija, A.M.I.C.E.

The Weights of Framed Girders and Roofs. By Joseph H. W. Buck, M.I.C.E.

A HISTORY OF THE ST. LOUIS BRIDGE—containing a full account of every step in its construction and erection, and including the theory of the Ribbed Arch and the Tests of Materials. By C. M. Woodard, Thayer Professor of Mathematics and Applied Mechanics, and Dean of the Polytechnic School of Washington University. St. Louis: G. J. Jones & Co. Price, cloth, $20.00; half bound, $25 00.

The title of this sumptuous volume idicates with sufficient fullness the scope of its contents. It is proper to add, however, that the style of the book, of its typography and illustrations, is quite commensurate with the great engineering work which it describes.

Of so great a work it is difficult to convey an adequate idea of its contents in the brief space of a *notice*, but an outline of the plan may be profitably presented.

The author at the outset discourses upon the "Basin and Regimen of the Mississippi River." This constitutes the first chapter. As it is a complete essay in itself, and a valuable one, it will be reprinted shortly as an article for this magazine. Apart from the questions of hydraulics which invest the natural history of such a great river with intense interest, the geographical features alone are sufficient to challenge the attention of intelligent readers everywhere. The area drained by the stream that flows under the great bridge is eighty-eight times the area of Massachusetts; or to state it in a more striking manner, the area whose drainage supplies the river at St. Louis equals the united areas of the basins of the Clyde, the Thames, the Seine, the Garonne, the Rhone, the Rhine, the Vistula, the Po, and the Elbe.

The "Historical sketch of attempts to bridge the Mississippi at St. Louis," and "The organization and work of the St. Louis and Illinois Bridge Company," which forms chapters 2d and 3d, are of local rather than general interest, although as the main features of other plans than the accepted one are discussed, and the objections to the present bridge are presented, the reader will doubtless be interested to find a certain likeness to the growth of other engineering projects of unusual magnitude.

The discussion over the merits and demerits of the plans is, perhaps, more fully expressed in the fourth chapter, in which the history of the organization of a rival company is related, and the final consolidation of the two.

"The West Abutment—the first report of the Chief Engineer," are the subjects of the fifth chapter. The practical beginning of the great work is completely described.

The illustrations distributed through the text are excellent and numerous. The character of the bed of the river is carefully analyzed, and the theory of the proposed bridge and of its supporting piers elaborately expounded.

Chapters six and seven relate to "Financial Matters, The Sinking of the Three Great Piers, Contracts, Controversies and Specifications." The portion relating to controversies is interesting reading, and all of it profitable.

Chapters eight and nine, on "the Construction of Anchor Bolts and Staves," and "Rolled Iron Work and Steel Envelopes" contain much valuable information regarding the tests applied to iron and steel members, of unusual dimensions and of varied composition. The experiments on chrome steel are of great interest and value. It is not merely the tabular statement of experimental trials that is here related, but the entire history of the solution of some exceedingly difficult problems in construction.

The encounter with similar difficulties is graphically related in the four succeeding chapters, all relating to the making and testing of separate important parts of the structure.

Chapter 10 records the "Reports and Suggestions of Mr. James Laurie, C.E.;" chapters 11 and 12 the "Manufacture of Steel Couplings," and chapter 13 to "The Work at the Keystone Shops."

With chapter 14 begins the story of the erection of the work. Chapters 15 and 16 continue the description, and detail the history of the closing of the west span, and then of the center and east spans in succession. The method of balancing the parts of the bridge on the pier is most fully described and illustrated by views taken at different stages of the progress.

The completion of the bridge and the account of the tests are recorded in chapter 17.

This is as nearly as possible the middle of the book. Eleven chapters more are devoted to the special discussion of subjects relating to the work, but which to have presented earlier would have encumbered the historical narrative.

These are the Sinking of the East Pier, Sinking of the West Pier, Sinking of the West Abutment, Stone Approaches, Ice Breakers, The Physiological Effects of Compressed Air (published from advance sheets in the January number of this Magazine), Investigations and Reports of the Board of Engineers of the United States Army, The Method of Erection, The Strength and Elasticity of Materials, The theory of the Ribbed Arch, Stability of the Foundations, Tables of Dimensions and Cost.

All of these special subjects are valuable to the engineer. One of them, The Theory of the Ribbed Arch, is a mathematical analysis of the structure.

The large plates, forty-seven in number, form a fitting embellishment to this beautiful volume.

SIMPLE HYDRAULIC FORMULÆ. By T. W. Stone, Civil Engineer. London: E. & F. N. Spon. Price $2.50.

This is a collection simply of the most useful formulæ in hydraulic engineering.

They are given under the following heads:

Flow over Weirs, Discharge Through Orifices, Discharge Through Short Tubes, Flow Through Long Pipes, and Distribution Pipes for Towns, Flow from Jets, Flow Through Canals, Rivers, and Aqueducts.

The appendices contain valuable tables. The whole forming a handy book, which, to the practical man, will be a welcome substitute for the large treatise.

WATER; ITS COMPOSITION, COLLECTION, AND DISTRIBUTION. By Joseph Parry, C.E. London: Frederick Warne & Co. Price $2.00.

"This book has been written (says the author) with a desire to give information that may be useful to the public in reference to Water and Water Supply; in deciding upon the merits of water schemes and methods of distribution, and in the selection, construction, and management of the numerous water appliances in which consumers are interested."

The several chapters treat in succession of the following subjects: Water, Composition of Water and Sources of Supply, Purification of Water, Modern Water Works, Distribution of Water, Water Rents, Appliances for Domestic Supplies, Waste of Water, Rural Supply, Water for Trade Purposes, Prevention of Waste.

AN ELEMENTARY TREATISE ON MENSURATION. By Geo. Bruce Halsted, A.B., A.M., and ex-Fellow of Princeton College; Ph.D. and ex-Fellow of Johns Hopkins University. Instructor in post graduate mathematics, Princeton College.

The author's preface reads thus: "This book is primarily the outcome of work on the subject while teaching it to large classes.

"The competent critic may recognize signs of a Berlin residence; but a considerable part, it is believed, is entirely new.

"Special mention must be made of the book's indebtedness to Dr. J. W. Davis, a classmate with me at the Columbia School of Mines." * * * * *

This seems but scant recognition of the fact

that the best parts of the book are but reprints of contributions to VAN NOSTRAND'S MAGAZINE, by J. Woodbridge Davis, C.E. Whole sections are reproduced verbatim, and the diagrams literally copied from Vols. XX. and XXI. of this Magazine, with no other hint of their origin than that afforded by the above reference to "Dr. J. W. Davis."

The most conspicuous of these borrowings are as follow: Pages 40 to 45 inclusive, on the measurement of Plane Areas, are mostly copied from the April No. of VAN NOSTRAND'S for 1879.

Pages 99–105, 107–120 on the measurement of Volumes, are mostly from the same source.

Chapter VI. on the Applicability of the Primoidal Formula, is mostly from a thesis of Mr. Davis, from which one of his magazine articles was condensed, and in the more important parts is literally copied. The last section of this chapter, one page only, seems to be the only original portion.

Chapters VII. and VIII., the last of the treatise proper, have been prepared from several sources: Boole's Calculus of Finite Differences, and the Mathematical Monthly among others, but by far the greater portion is from VAN NOSTRAND'S MAGAZINE for May, June, July, and October, 1879.

No objection is made to the contents of this book. The material is well selected and well enough arranged. It is exceeedingly well printed and but for the fact that borrowed material is made to pass for original work, it would be a creditable performance.

THE ELEMENTS OF FIELD FORTIFICATIONS. By J. B. Wheeler, Professor of Civil and Military Engineering in the United States Academy at West Point, Brevet-Colonel United States Army. New York: D. Van Nostrand Price $1.75.

This book was prepared for the use of the Cadets of the West Point Military Academy.

"The endeavor has been made," says the preface, "to state concisely and plainly the principles upon which the art of fortification is based, and to give all information likely to be of practical use to a young officer while serving in the field, all unnecessary details have been avoided, leaving explanations and illustrations of that kind to be introduced into the class room.

"The elementary form of the work and the method of treatment of the subject are based upon the assumption, that the readers of the book are beginners and know nothing of the principles of fortification."

The separate topics are:

General Principles and Definitions, Elements of the Profile of a Fortification, Dimensions and Inclinations given to the Lines and Slopes of a Parapet, The Trace of a Field Fortification, Field Works, Lines, Continued Lines, Lines with Intervals, Size of a Field Work, The Number of its Garrison and the Selection of its Trace. Construction of Field Works, Revetments, Defilade, Interior Arrangements made in a Field Works, Arrangement of the Parapet, Arrangements for Sheltering the Troops, For Affording Communications, For the Health and Comfort of the Garrison, Arrangement Exterior to the Parapet, Ditch Defenses, Obstacles, Sites upon Irregular Ground, Bridge Heads, Hasty Intrenchments, Attack and Defense of Field Fortifications, Siege Works, Military Bridges, Railroads.

The illustrations, ninety-seven in number, are distributed throughout the book.

The book looks inviting, even to readers having only a remote interest in military matters, by the appearance that it bears of imparting instruction in a simple, direct, and logical manner.

THE THEORY OF OUR NATIONAL EXISTENCE, AS SHOWN BY THE ACTION OF THE GOVERNMENT OF THE UNITED STATES SINCE 1861. By John C. Hurd, LL.D. Boston: Little, Brown & Co. Price $4.00.

The author is well known through his previous work, "The Law of Freedom and Bondage in the Unites States." The reputation already won by the author among jurists justifies the belief that the present work will be widely read.

ERRATUM.

ON page 173 of the present volume (Feb. No.) in the second column, the 25th and 26th lines (at the end of the notice of "Pressure of Earthwork"), should have been at the end of the previous article, so as to form 4th and 5th lines in the same column.

MISCELLANEOUS.

THE surveying party under General Fielding, which started in June last on the survey exploration for determining the best route for the proposed Trans-Australian railway from Roma, Queensland, to Fort Parker, in the Gulf of Carpentaria, has reached the latter end of the journey, and will probably return to Brisbane by the middle of this month. The results of the preliminary run through the country made by Mr. R. Watson, M.I.C.E., for the purposes of a report to the Queensland Government, was made in the first six months of last year, and the results were described in English papers, in September last. Queensland railways are 3ft. 6in. gauge, and before this great line is made it is to be hoped that some standard gauge for the whole of Australia will be arrived at by the several colonial Governments.

THE man who will render cranks unnecessary will confer a boon on the nation. In a few years cranks cost nearly as much as some of the ships that want them. Serious cracks were discovered last week in the necks of the midship high-pressure crank of the Jumma, as well as in the after crank. A spare crank is always kept in hand at Portsmouth, but, though it has been determined to work night and day to get it ready, the fitting of the eccentrics and other parts will take about a month to complete.